

**TÜV RHEINLAND
ENERGIE UND UMWELT GMBH**



Report on performance testing of the Air Pollution Monitor 2 (APM-2) measuring system manufactured by Comde-Derenda GmbH for the components suspended particulate matter PM₁₀ and PM_{2.5}

TÜV-report: 936/21219977/A
Cologne, 26th March 2014

www.umwelt-tuv.de



teu-service@de.tuv.com

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- Inspection of correct installation, function and calibration of continuously operating emission measuring instruments, including data evaluation and remote emission monitoring systems;
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- Performance testing of measuring systems for continuous monitoring of emissions and ambient air, and of electronic data evaluation and remote emission monitoring systems;
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**TÜV Rheinland Energie und Umwelt GmbH
D - 51105 Cologne, Am Grauen Stein, Tel: +49 221 806-5200, Fax: +49 221 806-1349**

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measuring system manufactured by Comde-Derenda GmbH for the components suspended particulate matter PM₁₀ and PM_{2.5}

Instrument tested: Air Pollution Monitor 2 (APM-2)

Manufacturer: Comde-Derenda GmbH
Kieler Straße 9
14532 Stahnsdorf
Germany

Test period: April 2012 until March 2014

Date of report: 26th March 2014

Report number: 936/21219977/A

Editor: Dipl.-Ing. Karsten Pletscher
Tel.: +49 221 806-2592
karsten.pletscher@de.tuv.com

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1. General and certification proposal

1.1 General

According to Directive 2008/50/EC dated 21st May 2008 (replaces air quality framework directive 96/62/EC dated 27th September 1996 including the related daughter directives 1999/30/EC, 2000/69/EC, 2002/3/EC as well as the Council decision 97/101/EC) on “ambient air quality and cleaner air for Europe”, the reference method for measuring the PM₁₀ concentration as per “Air quality – Determination of the PM₁₀ fraction of suspended particulate matter – Reference method and field test procedure to demonstrate reference equivalence of measurement methods of equality” given in EN 12341 and the reference method for measuring the PM_{2.5} concentration as per “Ambient air quality – Standard gravimetric measurement method for the determination of the PM_{2.5} mass fraction of suspended particulate matter” given in EN 14907 shall be used. A Member State can, in the case of particulate matter, use any other method which the Member State concerned can demonstrate displays a consistent relationship to the reference method. In that event the results achieved by that method must be corrected to produce results equivalent to those that would have been achieved by using the reference method (2008/50/EC, Annex VI, B).

The Guide “Demonstration of Equivalence of Ambient Air Monitoring Methods” [5] which was developed by an ad-hoc EC working group in January 2010

(Source: <http://ec.europa.eu/environment/air/quality/legislation/pdf/equivalence.pdf>)

describes a method for testing for equivalence of non-standardized measurement methods.

The requirements set out in the Guide for equivalence testing have been included in the last revision of the VDI Standards 4202, Sheet 1 and VDI 4203, Sheet 3.

In this performance testing the following limit values were applied:

	PM_{2.5}	PM₁₀
Daily limit DL (24 h)	Not defined	50 µg/m ³
Annual limit AL (1 a)	25 µg/m ³ *	40 µg/m ³

as well as for the calculations according to the Guide [5]

	PM_{2.5}	PM₁₀
Limit value	30 µg/m ³	50 µg/m ³

The 2002 VDI guideline 4202, Sheet 1 describes the “Minimum requirements for suitability tests for ambient air quality systems”. General parameters for the related tests are set out in VDI Standard 4203, Sheet 1 “Testing of automated measuring systems – General concepts” of October 2001 and further specified in VDI 4203, Sheet 3 “Testing of automated measuring systems – Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants” of August 2004.

VDI Standards 4202, Sheet 1 and 4203, Sheet 3 underwent extensive revision and were newly published in September 2010. Unfortunately, after this revision there are some ambiguities and contradictions in relation to the performance testing of particulate measuring systems as far as minimum requirements on the hand and the general relevance of test items on the other hand are concerned. The following test items require clarification:

6.1 5.3.2 Repeatability standard deviation at zero point

→ no minimum requirement defined

6.1 5.3.3 Repeatability standard deviation at reference point

→ not relevant to particulate measuring systems

6.1 5.3.4 Linearity (lack of fit)

→ not relevant to particulate measuring systems

6.1 5.3.7 Sensitivity coefficient of surrounding temperature

→ no minimum requirement defined

6.1 5.3.8 Sensitivity coefficient of supply voltage

→ no minimum requirement defined

6.1 5.3.11 Standard deviation from paired measurements

→ no minimum requirement defined

6.1 5.3.12 Long-term drift

→ no minimum requirement defined

6.1 5.3.13 Short-term drift

→ not relevant to particulate measuring systems

6.1 5.3.18 Overall uncertainty

→ not relevant to particulate measuring systems, covered by 5.4.10.

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In order to determine a concerted procedure for dealing with the inconsistencies in the guidelines, an official enquiry was directed to the relevant body in Germany.

The following procedure was suggested:

As before, the test items 5.3.2, 5.3.7, 5.3.8, 5.3.11, and 5.3.12 are evaluated based on the minimum requirements set out in VDI 4202, Sheet 1 of 2002 (i.e. using the reference values B₀, B₁, and B₂).

The test items 5.3.3, 5.3.4, 5.3.13, and 5.3.18 are omitted as they are not relevant to particulate measuring systems.

The relevant body in Germany approved of the suggested procedure by decisions of 27 June 2011 and 7 October 2011.

The reference values which shall be used according to the applied guidelines explicitly refer to the measured component PM₁₀. Therefore, the following reference values are suggested for the measured component PM_{2.5}:

	PM_{2.5}	PM₁₀
B ₀	2 µg/m ³	2 µg/m ³
B ₁	25 µg/m ³	40 µg/m ³
B ₂	200 µg/m ³	200 µg/m ³

B₁ shall merely be adjusted to the level of the limit value for the annual mean.

Comde-Derenda GmbH has commissioned TÜV Rheinland Energie und Umwelt GmbH to carry out a performance test of the Air Pollution Monitor (APM-2) measuring system for the components suspended particulate matter PM₁₀ and PM_{2.5}.

- VDI Standard 4202, Sheet 1, "Performance criteria for performance tests of automated ambient air measuring systems – Point-related measurement methods for gaseous and particulate air pollutants", September 2010/June 2002
- VDI Standard 4203, Sheet 3, "Testing of automated measuring systems – Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants", September 2010/August 2004
- Standard EN 12341, "Air quality – Determination of the PM₁₀ fraction of suspended particulate matter – Reference method and field test procedure to demonstrate reference equivalence of measurement methods of equality", German version EN 12341: 1998
- Standard EN 14907, "Ambient air quality – Standard gravimetric measurement method for the determination of the PM_{2.5} mass fraction of suspended particulate matter", German version EN 14907: 2005
- Guidance document "Demonstration of Equivalence of Ambient Air Monitoring Methods", English version of January 2010

The measuring system Air Pollution Monitor (APM-2) operates according to the principle of scattered light measurement. By means of a pump ambient air is sucked in via a PM₁₀-impactor inlet (3.3 l/min) and splitted into two partial streams by a virtual impactor. Via magnetic valves, either the aerosol out of the axial flow (enrichment mode for determination of PM₁₀-concentration) or the aerosol out of the side flow (normal mode for determination of PM_{2.5}-concentration) is lead to the measurement sensor. At this point, the PM₁₀- respectively PM_{2.5}-concentration is measured in switch-over mode by means of scattered light measurement technique.

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The tests were performed in the laboratory and during a field test that lasted several months.

The field test which lasted several months was performed at the test sites given in Table 1.

Table 1: *Description of test sites*

	Cologne, parking lot, winter	Bonn, street crossing, winter	Cologne, parking lot, summer	Rodenkirchen, motorway A555, summer
Period	11/2012 – 02/2013	02/2013 – 05/2013	05/2013 – 07/2013	07/2013 – 09/2013
No. of paired values: candidates	69	61	54	53
Characteristics	Urban background	Influenced by traffic	Urban background	Rural structure + motorway
Level of ambient air pollution	Average to high	Average to high	Low to average	Low

During the performance of the type approval test, the calculation algorithm for the measured PM values has been further optimized by the instrument manufacturer. For this the instrument software had to be revised and a new software version (Version 3.0.1) was provided during winter 2014. In order to qualify the now implemented modification of the calculation algorithm in the instrument software, all measured values of the comparison campaigns according to table 1 have been manually recalculated with the new calculation algorithm and re-evaluated. Furthermore an additional comparison campaign at the test site Cologne, parking lot with two candidates and the new software version (Version 3.0.1) was carried out for further qualification. Table 2 gives an overview on the additional campaign. The results of these additional investigations are presented in chapter 7 starting with page 194.

Table 2: *Description of test site (validation campaign 2014)*

	Cologne, parking lot, winter
Period	01/2014 – 03/2014
No. of paired values: candidates	53
Characteristics	Urban background
Level of ambient air pollution	Average to high

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The minimum requirements were fulfilled during performance testing.

TÜV Rheinland Energie und Umwelt GmbH therefore suggests its approval as a performance tested measuring system for continuous monitoring of ambient air pollution by suspended particulate matter PM₁₀ and PM_{2.5}.

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1.2 Certification proposal

Due to the positive results achieved, the following recommendation is put forward for the notification of the AMS as a performance-tested measuring system:

AMS designation:

Air Pollution Monitor 2 (APM-2) for suspended particulate matter PM₁₀ and PM_{2.5}

Manufacturer:

Comde-Derenda GmbH, Stahnsdorf

Field of application:

Continuous and parallel measurement of the PM₁₀ and PM_{2.5} fractions in ambient air (stationary operation).

Measuring ranges during performance testing:

Component	Certification range	Unit
PM ₁₀	0 – 1.000	µg/m ³
PM _{2.5}	0 – 1.000	µg/m ³

Software version:

3.0.1

Restriction:

None

Notes:

1. The requirements according to the guide "Demonstration of Equivalence of Ambient Air Monitoring Methods" are met for the measured components PM₁₀ and PM_{2.5} after application of the determined correction factors/terms.
2. The requirements on the equivalence test according to Standard EN 12341:1998 for PM₁₀ have not been met by the candidates.
3. The long-term drift of the sensitivity of the particle sensor could not be determined during the field test.
4. The measuring system can be telemetrically monitored, but not operated.
5. The measuring system determines the PM₁₀- and the PM_{2.5}-fraction of suspended particulate matter in an alternating way – within the scope of the type approval test, the switch-over between the two fractions has been carried out every two minutes.
6. The measuring system shall be calibrated on site with the gravimetric PM₁₀ reference method as per EN 12341 on a regular basis. Preferably a seasonal calibration rhythm is to follow.
7. The measuring system shall be calibrated on site with the gravimetric PM_{2.5} reference method as per EN 14907 on a regular basis. Preferably a seasonal calibration rhythm is to follow.
8. This report on the performance testing can be viewed on the internet at www.gal1.de.

Test report:

TÜV Rheinland Energie und Umwelt GmbH, Cologne
Report no.: 936/21219977/A of 26th March 2014

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1.3 Summary of test results

Performance criterion	Specification	Test result	Fulfilled	Page
4 Requirements on instrument design				
4.1 General requirements				
4.1.1 Measured value display	Shall be available.	The measuring system provides a display that shows the measured values.	yes	64
4.1.2 Easy maintenance	Necessary maintenance of the measuring systems should be possible without larger effort, if possible from outside.	Maintenance work can be carried out from the outside with commonly available tools and reasonable time and effort.	yes	66
4.1.3 Functional check	If the operation or the functional check of the measuring system requires particular instruments, they shall be considered as part of the measuring system and be applied in the corresponding sub-tests and included in the assessment.	All functions described in the operator's manual are available, can be activated, and work properly. The current instrument status is continuously monitored and different warning messages are displayed in the case of problems.	yes	70
4.1.4 Setup times and warm-up times	Shall be specified in the instruction manual.	Setup and warm-up times were determined.	yes	72
4.1.5 Instrument design	Shall be specified in the instruction manual.	The instrument design specifications listed in the operator's manual are complete and correct.	yes	73
4.1.6 Unintended adjustment	It shall be possible to secure the adjustment of the measuring system against illicit or unintended adjustment during operation.	The measuring system is secured against illicit or unintentional adjustments of instrument parameters. Additional protection against unauthorized access is provided by the lockable door of the weatherproof housing.	yes	74
4.1.7 Data output	The output signals shall be provided digitally and/or as analogue signals	The measured signals are stored on SD-card or offered digitally (via RS232).	yes	75

Performance criterion	Requirement	Test result	Fulfilled	Page
5. Performance criteria				
5.1 General	The manufacturer's specifications in the instruction manual shall not contradict the results of the performance test.	No differences between the instrument design and the descriptions given in the manuals were found.	yes	77
5.2 General requirements				
5.2.1 Certification ranges	Shall comply with the requirements of Table 1 of VDI Standard 4202, Sheet 1.	Assessment of AMS in the range of the relevant limit values is possible.	yes	78
5.2.2 Measuring range	The upper limit of measurement of the measuring systems shall be greater or equal to the upper limit of the certification range.	The upper limit of measurement is greater than the corresponding upper limit of the certification range.	yes	79
5.2.3 Negative output signals	Negative output signals or measured values may not be suppressed (life zero).	Negative output signals are directly displayed by the AMS and can be output via corresponding data outputs. Yet, they are not to be expected due to measuring principle and instrument design.	yes	80
5.2.4 Failure in the mains voltage	Uncontrolled emission of operation and calibration gas shall be avoided. The instrument parameters shall be secured by buffering against loss caused by failure in the mains voltage. When mains voltage returns, the instrument shall automatically reach the operation mode and start the measurement according to the operating instructions.	All parameters are secured against loss by buffering. When mains voltage returns the AMS returns to failure-free operation mode and automatically resumes measuring after re-stabilization of the photometer temperature and two-minutes zero air purging.	yes	81
5.2.5 Operating states	The measuring system shall allow the control of important operating states by telemetrically transmitted status signals.	The measuring systems can be monitored and operated extensively from an external PC via modem or router.	yes	82
5.2.6 Switch-over	Switch-over between measurement and functional check and/or calibration shall be possible telemetrically by computer control or manual intervention.	The measuring system can be monitored by the user directly or via remote control. A telemetric control is not yet implemented, but already planned for the future.	no	83
5.2.7 Maintenance interval	If possible 3 months, minimum 2 weeks.	The maintenance interval of 4 weeks has been determined by regular maintenance work.	yes	84

Performance criterion	Specification	Test result	Fulfilled	Page
5.2.8 Availability	Minimum 95 %.	The availability was 100 % for SN3 and 98.9 % for SN4 without test-related downtimes. Including test-related downtimes it was 91.6 % for SN3 and 90.5 % for SN4.	yes	85
5.2.9 Instrument software	The version of the instrument software to be tested shall be displayed during switch-on of the measuring system. The test institute shall be informed on changes in the instrument software, which have influence on the performance of the measuring system.	The version of the instrument software is shown in the display. The test institute is informed on any changes in the instrument software.	yes	87
5.3 Requirements on measuring systems for gaseous air pollutants				
5.3.1 General	Minimum requirement according to VDI 4202, Sheet 1.	The test was carried out on the basis of the performance criteria stated in VDI Standard 4202, Sheet 1 (September 2010). However, the test items 5.3.2, 5.3.7, 5.3.8, 5.3.11, and 5.3.12 were evaluated on the basis of the performance criteria stated in the 2002 version of VDI Standard 4202, Sheet 1 (i.e. applying the reference values B ₀ , B ₁ , and B ₂). The test items 5.3.3, 5.3.4, 5.3.13, and 5.3.18 were omitted as they are irrelevant to particulate measuring devices.	yes	90
5.3.2 Repeatability standard deviation at zero point	The repeatability standard deviation at zero point shall not exceed the requirements of Table 2 in the certification range according to Table 1 of VDI Standard 4202, Sheet 1 (September 2010). For PM: Max. B ₀ .	The tests resulted in detection limits of 0.03 µg/m³ (PM ₁₀) and <0.01 µg/m³ (PM _{2.5}) for System 1 (SN3), and 0.09 µg/m³ (PM ₁₀) and 0.10 µg/m³ (PM _{2.5}) for System 2 (SN4).	yes	92
5.3.3 Repeatability standard deviation at reference point	The repeatability standard deviation at reference point shall not exceed the requirements of Table 2 in the certification range according to Table 1 of VDI Standard 4202, Sheet 1 (September 2010).	Not applicable.	-	94

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Performance criterion	Specification	Test result	Fulfilled	Page
5.3.4 Linearity (lack of fit)	The analytical function describing the relationship between the output signal and the value of the air quality characteristic shall be linear.	Particulate measuring systems for PM ₁₀ shall be tested according to performance criterion 5.4.2 "Equivalency of the sampling system". Particulate measuring systems for PM _{2.5} shall be tested according to performance criterion 5.4.10 "Calculation of expanded uncertainty between systems under test".	-	95
5.3.5 Sensitivity coefficient of sample gas pressure	The sensitivity coefficient of the sample gas temperature at reference point shall not exceed the specifications of Table 2 of VDI Standard 4202, Sheet 1 (September 2010).	Not applicable.	-	96
5.3.6 Sensitivity coefficient of sample gas temperature	The sensitivity coefficient of the surrounding temperature at zero and reference point shall not exceed the specifications of Table 2 of VDI Standard 4202, Sheet 1 (September 2010).	Not applicable.	-	97
5.3.7 Sensitivity coefficient of surrounding temperature	The sensitivity coefficient of the surrounding temperature at zero and reference point shall not exceed the specifications of Table 2 of VDI Standard 4202, Sheet 1 (September 2010). For PM: Zero point value for ΔT_u of 15 K between +5 °C and +20 °C or 20 K between +20 °C and +40 °C shall not exceed B_0 . The measurement value in the range of B_1 shall not exceed $\pm 5 \%$ for ΔT_u of 15 K between +5 °C and +20 °C or for 20 K between +20 °C and +40 °C	The ambient temperature range tested at the AMS installation site was -20 °C to +50 °C. Looking at the values that were output by the AMS, the maximum dependence of ambient temperature in the range of -20 °C to +50 °C at zero was 0.1 µg/m³ for PM _{2.5} and 0.2 µg/m³ for PM ₁₀ . At reference point, no deviations > 2.7 % in relation to the default temperature of 20 °C were observed.	yes	98

Performance criterion	Specification	Test result	Fulfilled	Page
5.3.8 Sensitivity coefficient of supply voltage	The sensitivity coefficient of the electric voltage at reference point shall not exceed the specifications made in Table 2 of VDI Standard 4202, Sheet 1 (September 2010). For PM: Change in measured value at B ₁ maximum B ₀ within the voltage interval (230 +15/-20) V.	No deviations > 1.3 % in relation to the default value of 230 V due to changes in supply voltage were detected.	yes	102
5.3.9 Cross-sensitivity	The change in the measured value caused by interfering components in the sample gas shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010) at zero and reference point.	Not applicable.	-	104
5.3.10 Averaging effect	For gaseous components the measuring system shall allow the formation of hourly averages. The averaging effect shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010).	Not applicable.	-	105
5.3.11 Standard deviation from paired measurements	The standard deviation from paired measurements under field conditions shall be determined with two identical measuring systems by paired measurements in the field test. It shall not exceed the specifications stated in Table 2 of VDI Standard 4202, Sheet 1 (September 2010). For PM: RD ≥ 10 related to B ₁ .	In the field test, the reproducibility for the full dataset was 20 for PM _{2.5} and 16 for PM ₁₀ .	yes	106

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Performance criterion	Specification	Test result	Fulfilled	Page
5.3.12 Long-term drift	<p>The long-term drift at zero point and reference point shall not exceed the requirements of Table 2 in the field test of VDI Standard 4202, Sheet 1 (September 2010) in the field test.</p> <p>For PM:</p> <p>Zero point: within 24 h and within the maintenance interval a maximum of B₀.</p> <p>As reference point: within 24 h and within the maintenance interval a maximum 5 % of B₁.</p>	<p>For PM_{2.5}, the maximum deviation at zero point was -1.4 µg/m³ in relation to the previous value and 2.4 µg/m³ in relation to the start value. Thus, it lies within the permissible limits of B₀ = 2 µg/m³.</p> <p>For PM₁₀, the maximum deviation at zero point was 1.5 µg/m³ for in relation to the previous value and 2.7 µg/m³ in relation to the start value and thus related to the start value outside of the permissible limit of B₀ = 2 µg/m³. This deviation only occurred one time during the entire field test campaign, a cause could not be determined. There was no externally triggered adjustment of the measuring device.</p> <p>A regular external check of the sensitivity over the field test period could not be carried out, as suitable test equipment was not available before December 2013. As the devices have shown no drift effects during the permanent comparison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely abstain from this test point in future for type approval testing according to EN TS 16450 [9].</p>	no	109
5.3.13 Short-term drift	<p>The short-term drift at zero point and reference point shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010) within 12 h (for benzene 24 h) in the laboratory test and within 24 h in the field test.</p>	Not applicable.	-	115
5.3.14 Response time	<p>The response time (rise) of the measuring systems shall not exceed 180 s.</p> <p>The response time (fall) of the measuring systems shall not exceed 180 s.</p> <p>The difference between the response time (rise) and response time (fall) of the measuring system shall not exceed 10 % of response time (rise) or 10 s, whatever value is larger.</p>	Not applicable.	-	116

Performance criterion	Specification	Test result	Fulfilled	Page
5.3.15 Difference between sample and calibration port	The difference between the measured values obtained by feeding gas at the sample and calibration port shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010).	Not applicable.	-	117
5.3.16 Converter efficiency	In the case of measuring systems with a converter, the efficiency of the converter shall be at least 98 %.	Not applicable.	-	118
5.3.17 Increase of NO ₂ concentration due to residence in the AMS	In case of NO _x measuring systems, the increase of NO ₂ concentration due to residence in the measuring system shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010).	Not applicable.	-	119
5.3.18 Overall uncertainty	The expanded uncertainty of the measuring system shall be determined. The value determined shall not exceed the corresponding data quality objectives in the applicable EU Directives on air quality listed in Annex A, Table A1 of VDI Standard 4202, Sheet 1 (September 2010).	By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems. Please refer to module 5.4.10.	-	120
5.4 Requirements on measuring systems for particulate air pollutants				
5.4.1 General	Test according to the minimum requirement stated in Table 5 of VDI Standard 4202, Sheet 1. Furthermore, the particle mass concentration shall be related to a defined volume.	The test was carried out according to the minimum requirements set out in Table 5 of VDI Standard 4202, Sheet 1 (September 2010). The APM-2 measuring system is an optical measuring system which first determines the scattered light signal, induced by particles in a defined measured volume, and then converts the available information into concentration values by means of an algorithm. The measured signal for the particles is therefore related to a defined volume (measured volume).	yes	121

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Performance criterion	Specification	Test result	Fulfilled	Page
5.4.2 Equivalency of the sampling system	The equivalency to the reference method according to EN 12341 [T2] shall be demonstrated.	For SN3, the reference equivalence functions for the (uncorrected) datasets lie outside the limits of the respective acceptance envelope for all test sites with exception of Cologne, winter, for SN4 only the reference equivalence function for the field campaign Rodenkirchen is outside of the respective acceptance envelope. Moreover, the variation coefficient R^2 of the calculated reference equivalence function in the concentration range concerned is < 0.95 for all comparison campaigns with exception of Cologne, winter. The demonstration of equivalence according to EN 12341:1998 is thus not possible. Nevertheless, the equivalence test according to the EC-guide, which is relevant for the end user, is passed after application of the necessary correction factors for all test sites without restrictions (refer to 6.1 5.4.11 Application of correction factors and terms).	no	122
5.4.3 Reproducibility of the sampling systems	This shall be demonstrated in the field test for two identical systems according to EN 12341 [T2].	The two-sided confidence interval CI95 of max. $3.58 \mu\text{g}/\text{m}^3$ is below the permissible limit of $5 \mu\text{g}/\text{m}^3$.	yes	130
5.4.4 Calibration	The systems under test shall be calibrated in the field test by comparison measurements with the reference method according to EN 12341 and EN 14907. Here, the relationship between the output signal and the gravimetrically determined reference concentration shall be determined as a steady function.	A statistical correlation between the reference measuring method and the output signal could be demonstrated.	yes	136
5.4.5 Cross sensitivity	Shall not exceed 10 % of the limit value.	No deviation of the measured signal from the nominal value $> -1.1 \mu\text{g}/\text{m}^3$ caused by interference due to moisture in the sample could be observed for PM _{2.5} . For PM ₁₀ , no deviation of the measured signal from the nominal value $> 0.9 \mu\text{g}/\text{m}^3$ caused by interference due to moisture in the sample could be observed. The comparability of the candidates with the reference method according to the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods" [5] is ensured even for days with a relative humidity of $> 70 \%$.	yes	139

Performance criterion	Specification	Test result	Fulfilled	Page
5.4.6 Averaging effect	The measuring system shall allow the formation of 24 h mean values. The time of the sum of all filter changes within 24 h shall not exceed 1 % of this averaging time.	The measuring system allows the formation of valid daily mean values.	yes	143
5.4.7 Constancy of sample volumetric flow	$\pm 3 \%$ of the rated value during sampling; instantaneous values $\pm 5 \%$ of the rated value during sampling.	All determined daily mean values deviate less than $\pm 3 \%$ from the rated value and all instantaneous values deviate less than $\pm 5 \%$.	yes	144
5.4.8 Tightness of the measuring system	Leakage shall not exceed 1 % of the sample volume sucked.	The criterion for passing the leakage test, which has been specified by the manufacturer, (maximum pressure increase of 290 hPa in 5 min) proved to be an appropriate parameter for monitoring instrument tightness. The detected maximum leak rate of 10.4 ml/min is less than 1 % of the nominal flow rate which is 3.3 l/min.	yes	147
5.4.9 Determination of uncertainty between systems under test u_{bs}	Shall be determined according to chapter 9.5.3.1 of the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods" in the field test for at two identical systems.	The uncertainty between the candidates u_{bs} with a maximum of 1.04 $\mu\text{g}/\text{m}^3$ for PM _{2.5} and a maximum of 2.28 $\mu\text{g}/\text{m}^3$ for PM ₁₀ does not exceed the required value of 2.5 $\mu\text{g}/\text{m}^3$.	yes	150
5.4.10 Calculation of expanded uncertainty between systems under test	Determination of the expanded uncertainty of the candidates according to chapters 9.5.3.2ff of the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods".	Without application of correction factors, the determined uncertainties W_{CM} for PM _{2.5} for all datasets under consideration lie below the defined expanded relative uncertainty W_{dgo} of 25 % for suspended particulate matter. Without application of correction factors, the determined uncertainties W_{CM} for PM ₁₀ for SN3 are for all datasets above the defined expanded relative uncertainty W_{dgo} of 25 % with exception of Cologne, Winter, for SN4 the data set Rodenkirchen, Summer and for both candidates together the data set $\geq 30 \mu\text{g}/\text{m}^3$ are also above the defined expanded relative uncertainty W_{dgo} of 25 % for suspended particulate matter. Correction factors shall be applied according to chapter 6.1 5.4.11 Application of correction factors and terms.	no	162

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Performance criterion	Specification	Test result	Fulfilled	Page
5.4.11 Application of correction factors and terms	If the maximum expanded uncertainty of the systems under test exceeds the data quality objectives according to the European Directive on ambient air quality [8], the application of correction factors and terms is allowed. Values corrected shall meet the requirements of chapter 9.5.3.2 ff. of the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods".	Due to application of the correction factors, the candidates meet the requirements on data quality of ambient air quality measurements for all datasets for PM _{2.5} and PM ₁₀ . For PM _{2.5} , the requirements are met even without application of correction factors. The correction of slope nevertheless leads to an improvement of the expanded measurement uncertainties of the full data comparison.	yes	185
5.5 Requirements on multiple-component measuring systems	Shall comply with the requirements set for each component also in the case of simultaneous operation of all measuring channels.	Upon assessing the minimum requirements, the measured values for both components were available at the same time (alternating every two minutes between the measurement channels PM ₁₀ and PM _{2.5}).	yes	193

2. Task definition

2.1 Nature of test

Comde-Derenda GmbH has commissioned TÜV Rheinland Energie und Umwelt GmbH to carry out the type-approval test of the Air Pollution Monitor 2 (APM-2) measuring. The test was performed as a complete type approval test.

2.2 Objective

The measuring system shall determine the concentrations of suspended particulate matter PM₁₀ and PM_{2.5} within a concentration range of 0 to 1.000 µg/m³.

The performance test was carried out in accordance with the current standards for performance tests and with regard to the most recent developments.

The testing was performed with respect to the following standards:

- VDI Standard 4202, Sheet 1, "Performance criteria for performance tests of automated ambient air measuring systems – Point-related measurement methods for gaseous and particulate air pollutants", September 2010/June 2002 [1]
- VDI Standard 4203, Sheet 3, "Testing of automated measuring systems – Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants", September 2010/August 2004 [2]
- European Standard EN 12341, "Air quality – Determination of the PM₁₀ fraction of suspended particulate matter – Reference method and field test procedure to demonstrate reference equivalence of measurement methods of equality", German version EN 12341: 1998 [3]
- European Standard EN 14907, "Ambient air quality – Standard gravimetric measurement method for the determination of the PM_{2.5} mass fraction of suspended particulate matter", German version EN 14907: 2005 [4]
- Guidance document "Demonstration of Equivalence of Ambient Air Monitoring Methods", English Version: January 2010 [5]

3. Description of the AMS tested

3.1 Measuring principle

The measuring system Air Pollution Monitor 2 (APM-2) determines the concentrations of suspended particulate matter PM₁₀ and PM_{2.5} according to the measuring principle of scattered light measurement.

The implemented measuring method utilizes the physical characteristics of light scattering at micro particles. The used scattered light / photometer unit consists of an intensity-stabilized laser diode and a semiconductor photo detector. Both components are arranged to each other in an angle of 90°, thus it is a mono-angle scattered light sensor. The light, reflected by particles in an exactly defined measuring volume, is measured by the detector. The photo detector generates a corresponding voltage signal (0-5 V), which is then low-noise amplified and is a direct measure for the mass concentration of the aerosol in the measured volume. For zero point adjustment, filtered air is lead to the scattered light sensor in periodic intervals via a switching appliance.

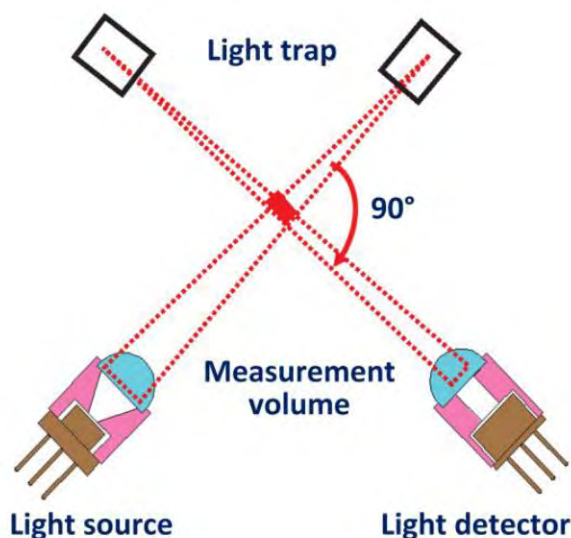


Figure 1: Operating principle of photometer unit

In order to exclude temperature dependency of the photometer signal, the photometer is installed in a case, which is thermally isolated and heated with a heating block, controlled on a temperature of 40 °C.

The physics of light scattering at particles causes, that aerosols with a diameter in the range of the used light wave length scatter the light in most efficient way, related to their mass, i.e. deliver the biggest contribution to the measured signal. For the utilized wavelength of approx. 650 nm, the maximum of sensitivity is in the particle size range between 0.5 and 1 µm. Because of that characteristic, the use of simple scattered light photometry for the measurement of PM₁₀-concentration is limited, as the measured signal is mainly dominated by the PM_{2.5}-fraction.

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For the measurement of the fraction PM₁₀, the complementary coarse fraction PM_{2.5-10} contributes significantly less to the scattered light signal (in relation to the mass), thus being underrepresented during the measurement. The sensitivity deficit for the coarse fraction is compensated in the device by a simple method – by selective enrichment of the concentration PM_{2.5-10} by the factor $3.3 / 0.2 = 16.5$ using a virtual impactor, which is arranged upstream of the scattered light sensor. The enrichment of concentration is equivalent to an increase of sensitivity of the photometry for the PM_{2.5-10} fraction.

The virtual impactor is located on the top of the case and is connected to the impactor inlet via the sampling tube. The ambient air (Q1), sucked in with 3.3 l/min using the integral pump, is divided into two partial streams by the virtual impactor. The division occurs in the area of two nozzles, which are arranged oppositely. The side flow Q2 (3.1 l/min) is hereby sucked between both nozzles perpendicular to the entering air stream. Particles, which do not follow the side flow due to their mass inertia, keep their path and thus get into the lower axial flow Q3 (0.2 l/min). Thus there is the separation into the side flow with only smaller and lighter particles of the fraction and the axial flow with the particle size und PM₁₀. Via low loss switching appliances (pinch valves with straight passage), either the aerosol out of the axial flow (enrichment mode) or out of the side flow (normal mode) enters the scattered light sensor. During the enrichment mode, the APM-2 determines the PM₁₀-concentration, during the normal mode it determines the PM_{2.5}-concentration. For zero point adjustment, filtered air is lead to the scattered light sensor in periodic intervals via a switching appliance.

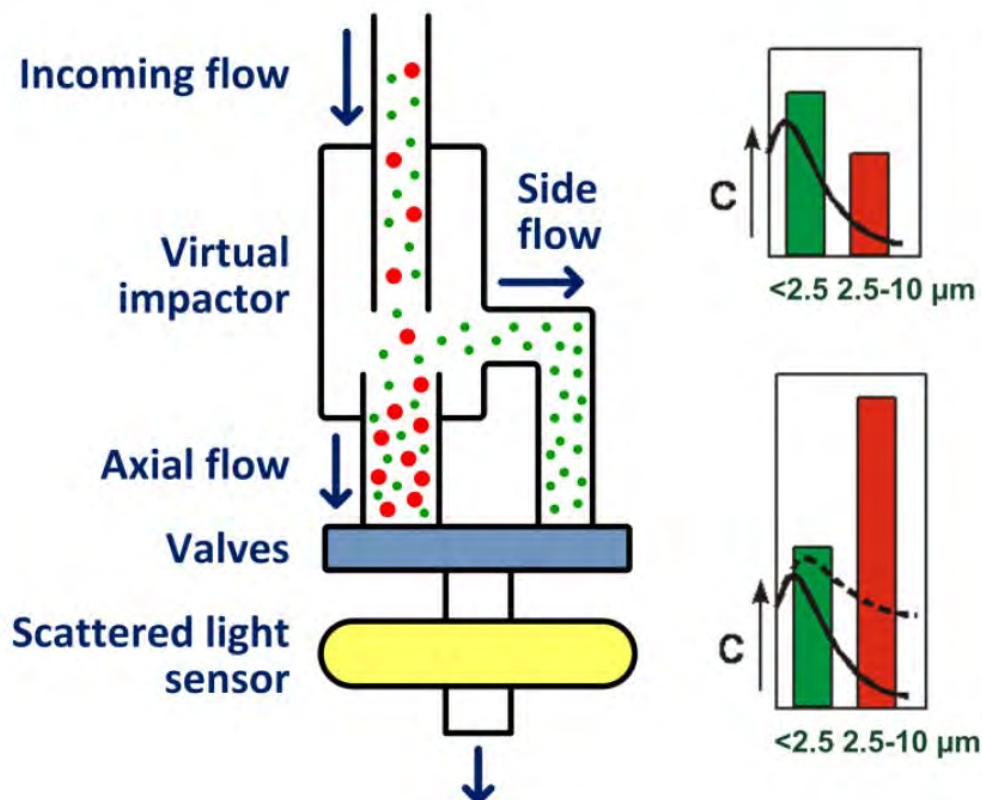


Figure 2: Operating principle of the virtual impactor

3.2 Principle of operation

The sample passes the PM₁₀-sampling inlet with a flow rate of 3.3 l/min and the sampling tube, which connects the sampling inlet with the virtual impactor. Inside of the virtual impactor, the sampled air is divided in two partial streams. Via magnetic valves, either the aerosol out of the axial flow (enrichment mode) or out of the side flow (normal mode) enters the scattered light sensor, where the measurement itself happens. During the type approval test, the measuring system was operated in switch mode between PM₁₀ and PM_{2.5} with a respective interval time of 2 min. Furthermore once per hour, zero air purging for approx. 2 min is performed for zero point adjustment – this is indicated in the display with „Flush“. The determined measured data are stored in the instrument memory as well as – if installed – on a SD-card.

Figure 3 shows the overview schematic of APM-2.

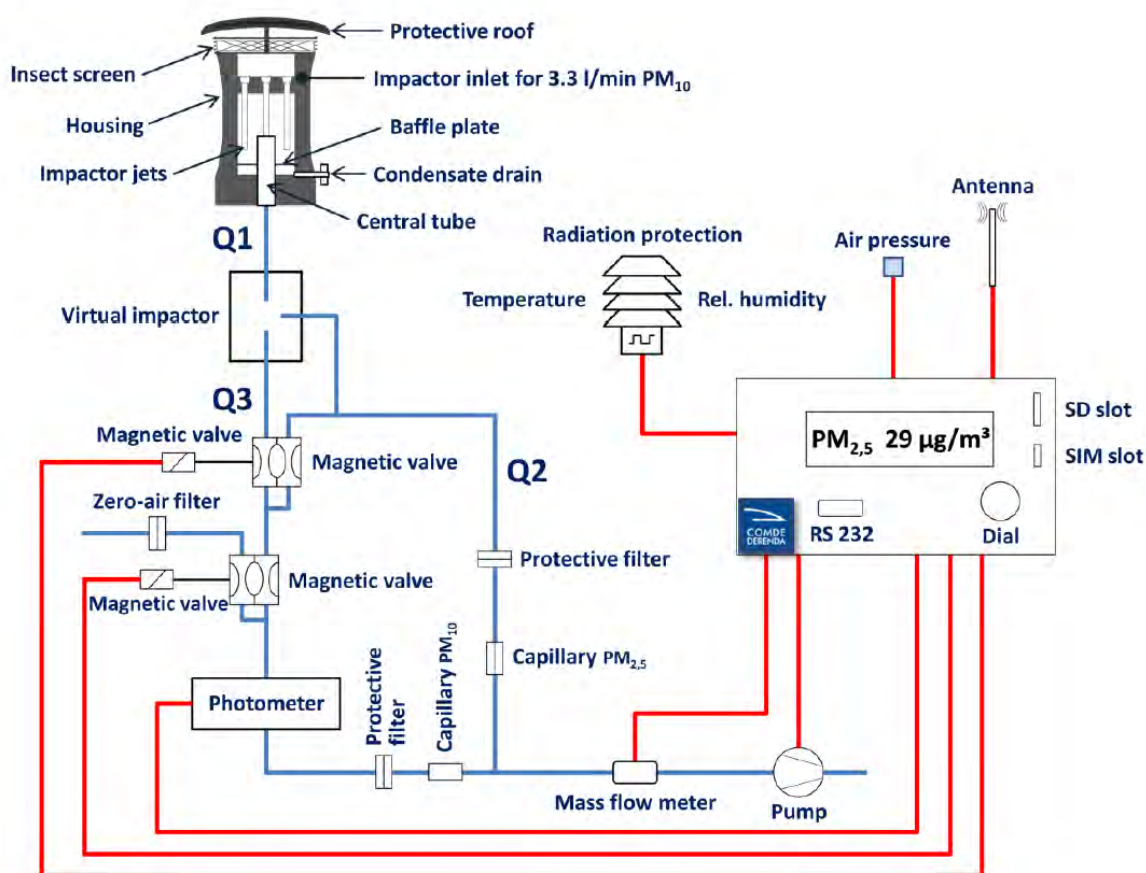


Figure 3: Overview schematic of APM-2

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3.3 AMS scope and setup

The APM-2 measuring system for the measurement of ambient air pollution through suspended particulate matter is based upon the measurement principle of scattered light.

The tested measuring system consists of a PM10-sampling inlet, the sampling tube, the virtual impactor, the measuring device with control unit and scattered light / photometer unit, the ambient and manual in German respectively English language.



Figure 4: Overview on complete system APM-2

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Figure 5: PM_{10} -sampling inlet for APM-2



Figure 6: Virtual impactor for APM-2

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Figure 7: View on APM-2 (front door open)



Figure 8: View on APM-2 (rear door open)

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Figure 9: Measuring systems APM-2 on measurement cabinet

The system is controlled and operated directly via the control unit with a Jog-Dial on the front of the device. Measured data are stored in the internal memory or on a SD-card – data transmission via RS232-interface is also possible (serial or Bayern-Hessen-Protocol). The operator can request measured data and system information, change parameters as well as perform tests for checking the correct operation of the measuring system.

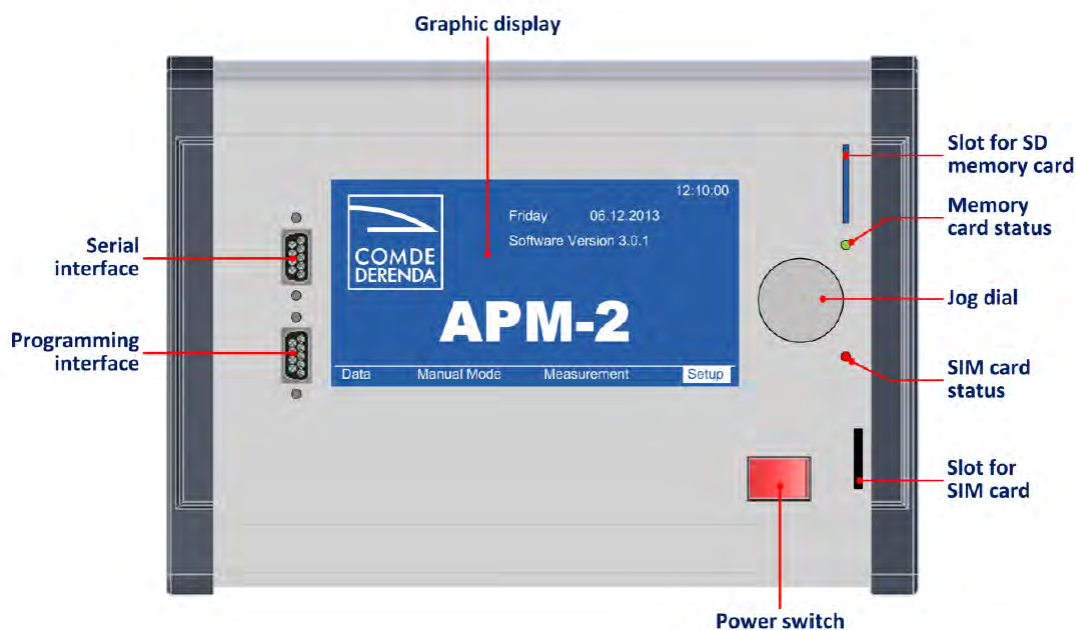


Figure 10: Control unit

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On top level one can find the main window of the operator display – starting from here one can navigate into the respective submenus via Jog-Dial. Furthermore current date and time and the installed software version are displayed.

- | | |
|---------------------|--|
| Menu „Data“: | In this menu one finds all functionalities with respect to data storage (internally or SD-card).

Furthermore one can access the software update functionalities via this menu. |
| Menu „Manual Mode“: | Here one can find the possibility to manually start the functionalities PM _{2.5} -measurement, PM ₁₀ -measurement and Purging. The chosen options will operate as long until they are interrupted again by the operator. This menu is mainly dedicated to service technicians for functional checks. |
| Menu „Measurement“: | A measurement is initiated by clicking on. |
| Menu „Setup“: | Via the menu „Setup“ the instrument parameters are set or tests for the correct operation are performed, e.g. language, date/time, check of sensitivity of photometer (test gas box), leak test, data transmission, system information, instrument settings (for service only, protected with factory password) and measurement parameters (PM _{2.5} , PM ₁₀ or switch mode, nominal temperature for heater block, interval for switch mode....) |

Figure 11 gives an overview on the structure of the menu for APM-2.

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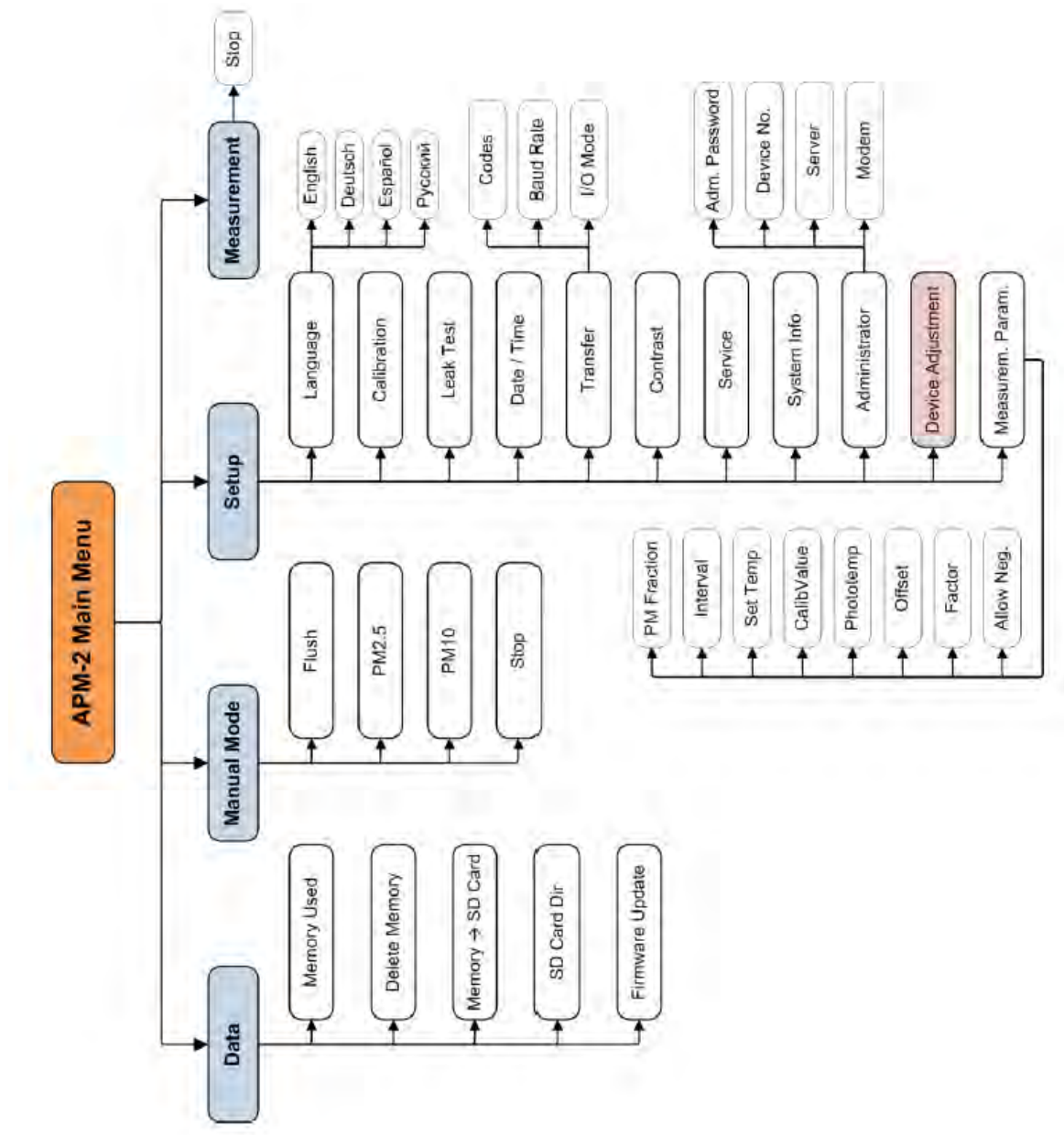


Figure 11: Structure of menu APM-2

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Besides the direct communication via Jog-Dial and instrument display, there is also the possibility to communicate with the measuring system via RS232 (serial interface, Bayern-Hessen-Protocol). Measured data can e.g. be recorded on a PC in a simple way via RS232 and a terminal software. During the type approval test, the measured data have been accessed by download the measured data stored on the SD-card.

For external check of the zero point of the measuring system, a zero filter is installed at the instrument inlet. The use of this filter allows the supply of particulate-free air.



Figure 12: Zero filter

For external check of the sensitivity of the photometer, the instrument's manufacturer has developed the following optional test method:

By offering propane to the photometer, a scattered light signal in the range of 300 - 400 mV (corresponds to an aerosol concentration of approx. 70 µg/m³) is induced. The stability of that signal is taken as a measure for the stability of the sensitivity. During an investigation on the repeatability, a standard deviation smaller than 1 % of the mean of the measured values could be determined in 15 measurements (refer to Table 3), so that the test method itself is to be considered sufficiently stable and reproducible.

Table 3: *Test on repeatability with test gas box*

Measurement	Time	Measured value [mV]
1	8:48	363
2	8:54	366
3	9:02	370
4	9:09	370
5	9:16	369
6	9:28	368
7	9:33	364
8	9:40	367
9	9:48	365
10	9:57	369
11	10:05	363
12	10:14	372
13	10:22	373
14	10:30	364
15	10:37	370
No. of values		15
Mean value		367.53
Standard deviation s_{x0}		3.25
Detection limit X [% of mean value]		1.90

Unfortunately the test method was not available before December 2013, so that the necessary tests at the reference point in the lab (climate chamber, mains voltage) could be carried out, but there are no long term drift investigations at the reference point available from the field test. As the devices have shown no drift effects during the permanent comparison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely abstain from this test point in future for type approval testing according to EN TS 16450 [9].

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Figure 13: Test gas box for checking the sensitivity



Figure 14: Test set-up APM-2 + test gas box

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For checking the tightness of the measuring device, a test appliance for tightness check is available. A vacuum is created in the device with the help of the instrument's pump and after switching off the pump, the rise in pressure over a time period of five minutes is monitored. In case of a rise in pressure > 290 hPa, the test on tightness is regarded as failed.



Figure 15: Test appliance for tightness check

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Table 4 contains a list of important device-related characteristics of the APM-2 measuring system for suspended particulate matter in the ambient air

Table 4: *Device-related data of the APM-2 (manufacturer's data)*

Dimensions / Weight	APM-2
Measuring system	320 x 560 x 270 mm / 15 kg
Sampling line	0.5 m between inlet and virtual impactor, customized lengths available on request
Sampling inlet	PM ₁₀ , general shape and manufacture according to DIN EN 12341, downscaled to 3.3 l/min
Power requirements	230 V, 50/60 Hz
Power input	ca. 80 W
Ambient conditions	
Temperature	-20 to +50 °C
Humidity	Outdoor-assembly, protection class IP65
Sample flow rate (Inlet)	3.3 l/min
Virtual impactor	
Side flow	3.1 l/min, PM _{2.5}
Axial flow	0.2 l/min, PM ₁₀
Aerosol sensor	
Measuring principle	Scattered light, One-angle (90°)
Nominal temperature photometer	40 °C
Measuring range	0 – 1000 µg/m³
Resolution	1 µg/m³
Operating method	During type approval test PM ₁₀ and PM _{2.5} in switch mode with switching interval of 2 min, different switching intervals (5,10 and 15 min) as well as option to single operation of either PM ₁₀ or PM _{2.5} are available
Storage capacity data (internal)	3.5 MB corresponds to 27,000 data sets, non-volatile ring buffer
Device inputs and outputs	1 x SD-card for storage of measured values 1 x RS232 interface for communication via serial interface / Bayern-Hessen-Protocol 1 x RS232 interface as programming interface (service only)
Status signals / Error messages	Available (manual, chapter 11)

4. Test programme

4.1 General

The performance test was carried out with two identical devices with the serial numbers SN3 and SN4.

The test was started in the year 2012 with software version 1.3. During the test work, the software was constantly developed and optimized, especially for the implementation of the test gas measurement.

With start of the field test in November 2012, the software version 2.1.0 was installed, updated to version 2.3.1 in February 2013 before the campaign „Bonn, winter“ and updated again to version 2.5.2 in June 2013 before the campaign „Cologne, summer“. This version was kept over the complete remaining field test (Cologne, summer and Rodenkirchen).

All implemented modification until version 2.5.2 are related in first line to the implementation of the test gas measurement and have no impact on the performance of the measuring system (refer to Table 5).

For the outstanding lab investigations at the reference point, the software version 3.0.0.d. respectively 3.0.1 was finally made available in December 2013 respectively January 2014.

These software versions contain an optimization of the calculation algorithm by introducing a linearity correction for the measured PM values. As this modification has an impact on the formation of measured values, the following measures for qualification of the new software – in addition to the outstanding lab investigations – have been agreed upon:

All available measured values of the four past comparison campaigns have been re-calculated manually with the new calculation algorithm and evaluated again. The results of these investigations can be found in chapter 6.1 5.4.10 Calculation of expanded uncertainty between systems under test.

Furthermore an additional comparison campaign at the test site Cologne, parking lot has been conducted with two candidates and the new software version for qualification. For this the following test program was carried out in detail:

- Performance of a comparison campaign with at minimum 40 valid data pairs reference vs. candidate
- Determination of the in-between uncertainty for the candidates u_{bs} according to the Guide
- Calculation of the expanded uncertainty of the candidates according to the Guide
- Application of the correction factors and terms determined in chapter 6.1 5.4.11 Application of correction factors and terms
- Re-calculation of the equivalence for the 4 data sets of the type approval at hand + additional data set from the validation campaign „Cologne, winter 2014“ according to the approach of chapter „8.2 Suitability test“ of EN/TS 16450 [9]

The results of the additional tests can be found in chapter 7 Investigations for the validation of the instrument software 3.0.1.

Table 5 gives an overview on the software releases during the type approval test and the changes between the different versions.

Table 5: *Overview of software releases during the type approval test*

Version	Description of changes	Status during type approval test
1.3	Start version	Lab test
2.0.0	<ul style="list-style-type: none"> • Process control optimized, as crashes during active heating were possible • Bug fix for volume flow calibration • Data transmission either on request (BH) or on regular base • Internal storage, which can later be transferred to the SD-card 	Not installed
2.1.0	<ul style="list-style-type: none"> • Implementation test gas measurement with-CO₂ 	Field test campaign 1
2.2.2	<ul style="list-style-type: none"> • Decimal place added for „SpülOffset“, „Gas-Offset“, „ugM³_PM2.5“ and „ugM³_PM10“ • CO₂-Test: 2 seconds break between evacuation and filling 	Not installed
2.3.0	<ul style="list-style-type: none"> • CO₂-Test: Pre-measurement with 67 % instead of 100 % pump voltage 	Not installed
2.3.1	<ul style="list-style-type: none"> • CO₂-Test: CO₂-pre-measurement only 20 s instead of 40 s 	Field test campaign 2
2.4.0	<ul style="list-style-type: none"> • GPRS-Modem can be used internally • Last concentration before purging is kept during purging in the BH-protocol • Flagging of purge step by „5“ in the BH-operational status 	Not installed
2.5.0	<ul style="list-style-type: none"> • New test gas measurement – without bag, 3times exchange with zero air, propane instead of CO₂ • Test gas timeline: 50 s zero air, 20 s propane with pump, 50 s propane without pump • Test gas display in mV with 2 decimals 	Not installed

2.5.1	<ul style="list-style-type: none"> • Test gas measurement: Standard deviation implemented • Test gas measurement: Repeating through „Start“ in the same menu 	Not installed
2.5.2	<ul style="list-style-type: none"> • Test gas timeline now 60-10-50 s • Test gas display in mV with 1 decimal 	Field test campaign 3 and 4
2.5.3	<ul style="list-style-type: none"> • Graphical improvements in test gas menu • Stop button in test gas menu 	Not installed
2.5.5	<ul style="list-style-type: none"> • In the test gas menu, the magnetic valve is switched to zero air, so that no propane can outpour (provided that the bypass is closed) 	Not installed
3.0.0.b	<ul style="list-style-type: none"> • Calibration function for barometer developed • Linearity correction implemented • Error display as superposed window • Calibration factor for photometer implemented • Factory-calibration of ADC-input now possible • Display of negative measured values can be switched on/off as an option • Leak test implemented 	Not installed
3.0.0.d	<ul style="list-style-type: none"> • Optional inversion of valve PM_{2.5}/PM₁₀ during test gas measurements 	Test gas measurements for lab test
3.0.1	<ul style="list-style-type: none"> • Leak test shows leak rate • Leak test: Vacuum pressure is determined a couple of seconds after switching off the pump • Communication via serial interface stabilized 	Campaign 5 for validation 3.0.1

The reliability of operation of the measuring system is increased continuously by the modifications. No significant impact on the instrument performance is to be expected for the changes up to version 3.0.0.b. The implemented modification in the calculation algorithm since version 3.0.0.b has been validated through an extensive test program (refer to chapter 7 starting with page 194 in this report).

The test comprised of a laboratory test for the assessment of performance characteristics as well as a field test, conducted over several months and at various field sites.

All obtained concentrations are given in µg/m³ (operating conditions). Additionally, the PM₁₀ concentrations for evaluation according to Standard EN 12341 for standard conditions are given in µg/m³ (273 K, 101.3 kPa) as well.

In the following report, the performance criteria according to the considered Standards [1, 2, 3, 4, 5] are stated in the caption of each test item with number and wording.

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4.2 Laboratory test

The laboratory test was carried out with two identical devices of the type APM-2 with the serial numbers SN3 and SN4. In conformity with the applicable standards [1, 2], the following performance criteria were tested in the laboratory:

- Description of device functions
- Determination of detection limit
- Dependence of zero point / sensitivity on ambient temperature
- Dependence of sensitivity on mains voltage

In the laboratory test, the following devices were used for the determination of performance characteristics

- climatic chamber (temperature range from -20 °C to +50 °C, accuracy better than 1 °C)
- Isolation transformer
- 1 mass flow meter Model 4043 (Manufacturer: TSI)
- Zero filter for external zero point check
- Test gas box (propane)
- Test appliance for tightness check

The recording of measurement values at zero point was performed by device-internal recording on the SD-card

For external check of the sensitivity of the photometer, the instrument's manufacturer has developed the following optional test method:

By offering propane to the photometer, a scattered light signal in the range of 300 - 400 mV (corresponds to an aerosol concentration of approx. 70 µg/m³) is induced. The stability of that signal is taken as a measure for the stability of the sensitivity.

The results of the laboratory tests are summarized in chapter 6.

4.3 Field test

The field test was carried out with two identical measuring systems:

System 1: SN3

System 2: SN4

The following performance criteria were tested in the field:

- Comparability of the systems under test according to the Guide “Demonstration of Equivalence of Ambient Air Monitoring Methods”
- Comparability of the systems under test with the reference method according to the Guide “Demonstration of Equivalence of Ambient Air Monitoring Methods”
- Check of constancy of the volume flow rate
- Calibration capability, analytical function
- Reproducibility
- Zero drift and sensitivity drift*
- Leak tightness of the sampling system
- Dependence of the measured values on sample humidity
- Maintenance interval
- Availability
- Total uncertainty of tested systems

* Unfortunately the test method was not available before December 2013, so that the necessary tests at the reference point in the lab (climate chamber, mains voltage) could be carried out, but there are no long term drift investigations at the reference point available from the field test. As the devices have shown no drift effects during the permanent comparison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely abstain from this test point in future for type approval testing according to EN TS 16450 [9].

The following auxiliary devices were used during the field test:

- TÜV Rheinland measuring cabinet, air conditioned to approx. 20 °C
- Weather station (WS 500 of ELV Elektronik AG) for the detection of meteorological parameters such as ambient temperature, atmospheric pressure, humidity, wind velocity, wind direction and amount of precipitation.
- 2 reference measuring systems LVS3 for PM₁₀ as per item 5
- 2 reference measuring systems LVS3 for PM_{2.5} as per item 5
- 1 gas meter, dry
- 1 mass flow meter Model 4043 (Manufacturer: TSI)
- Power consumption measuring device type Metratester 5 (manufactured by Gossen Metrawatt)
- Zero filter for external zero point checks

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The recording of measurement values was performed by device-internal recording on the SD-card

During the field test, two APM-2 systems and two reference systems for PM_{2.5} and PM₁₀ were operated simultaneously for a period of 24 hours. The reference system operates discontinuously, that is to say the filter needs to be changed manually after sampling.

During the testing, the impaction plates of the PM₁₀ and PM_{2.5} sampling heads of the reference systems were cleaned and lubricated with silicone grease approx. every 2 weeks in order to ensure a safe separation and deposition of particulates. The sampling inlets of the candidates were cleaned approx. every 4 weeks according to manufacturer's information. The sampling head shall always be cleaned in accordance with the instructions provided by the manufacturer. Local concentrations of suspended particulate matter shall also be considered in this procedure.

Before and after each change of test site, the flow rate was tested on each candidate as well as on each reference system with a dry gas meter and a mass flow meter, which connects to the system inlet via hose line.

Test sites and AMS placement

For the field test at the test sites Cologne and Bonn, the measuring systems were installed completely outside on the roof of the measuring cabinet. At these sites, the entire reference equipment (LVS3) was installed outdoors on the roof of the cabinet as well. The installation of the candidates and the reference devices at test site Rodenkirchen was carried out on platforms with approx. 0.5 m height.

The field test was carried out at the following test sites:

Table 6: Field test sites

No.	Test site	Period	Characterization
1	Cologne, winter	11/2012 – 02/2013	Urban background
2	Bonn, road junction, winter	02/2013 – 05/2013	Influence of traffic
3	Cologne, summer	05/2013 – 07/2013	Urban background
4	Rodenkirchen, summer	07/2013 – 09/2013	Rural structure + influence of traffic
5	Cologne, winter*	01/2014 – 03/2014	Urban background

* Validation campaign for software 3.0.1, refer to chapter 7 Investigations for the validation of the instrument software 3.0.1 Investigations for the validation of the instrument software 3.0.1 at page 194.

Figure 16 to Figure 25 show the course of PM concentrations at the measuring locations in the field as recorded by the reference measuring systems.

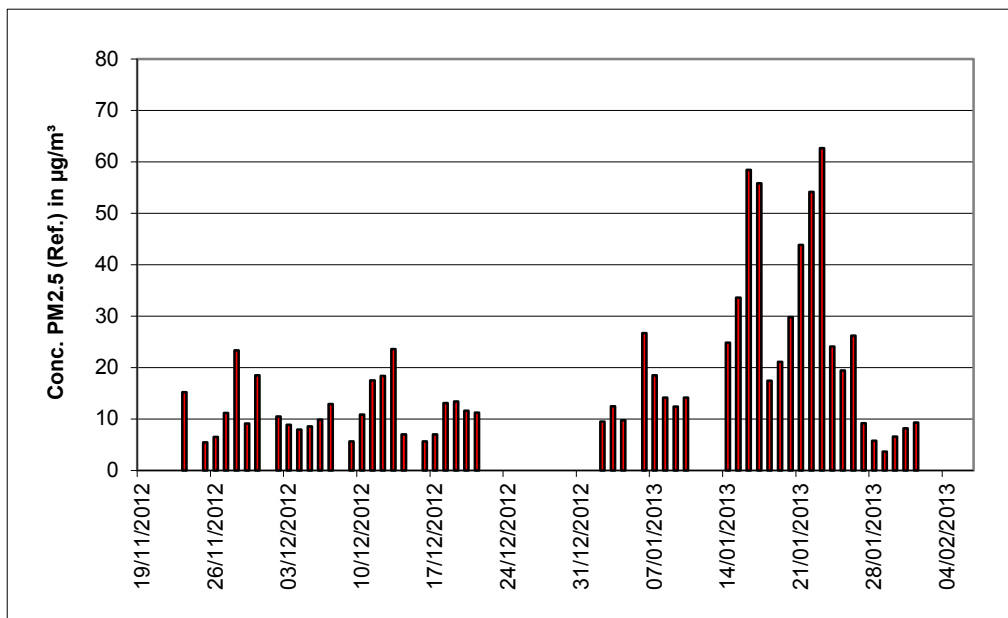


Figure 16: Course of PM_{2.5} concentrations (reference) at test site "Cologne, winter"

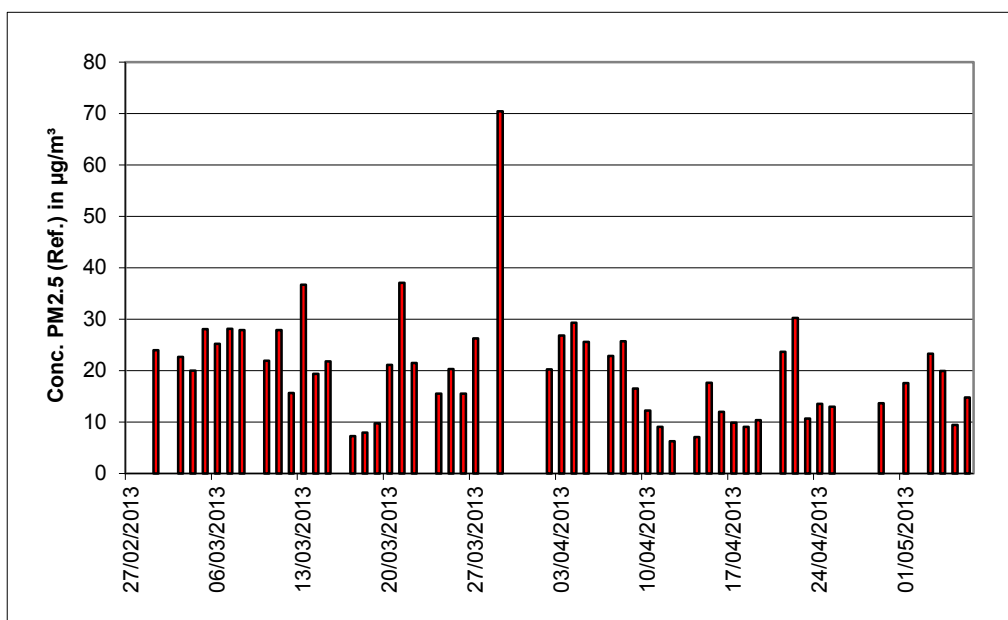


Figure 17: Course of PM_{2.5} concentrations (reference) at test site "Bonn, winter"

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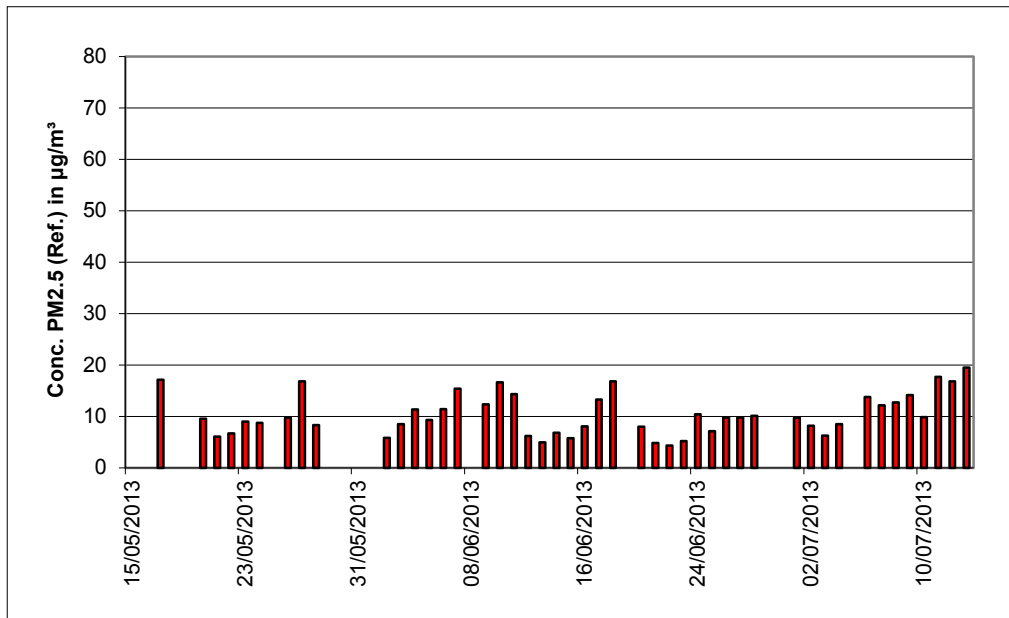


Figure 18: Course of PM_{2.5} concentrations (reference) at test site "Cologne, summer"

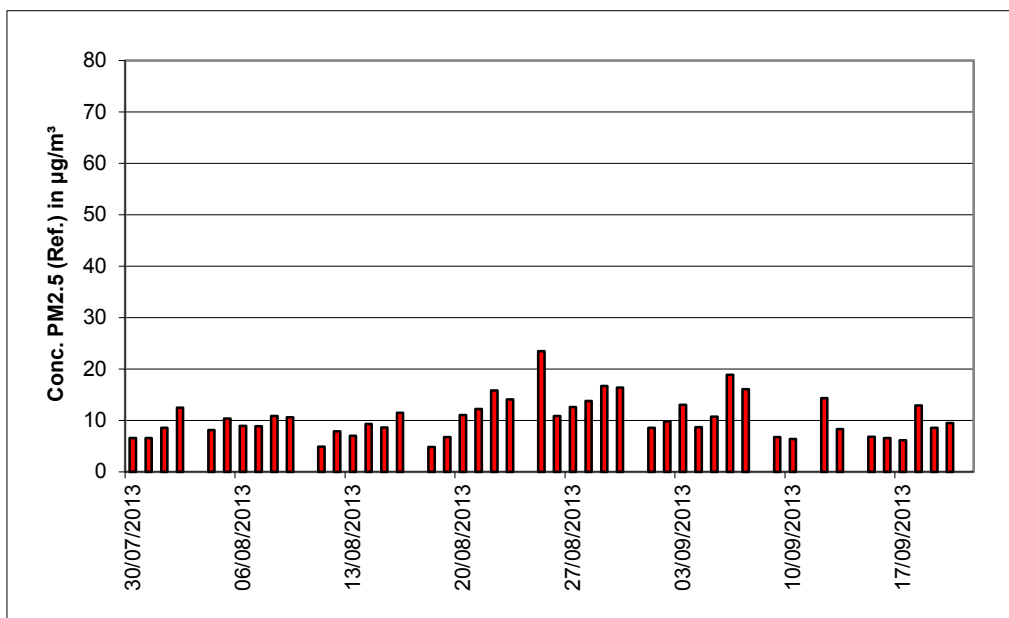


Figure 19: Course of PM_{2.5} concentrations (reference) at test site "Rodenkirchen, summer"

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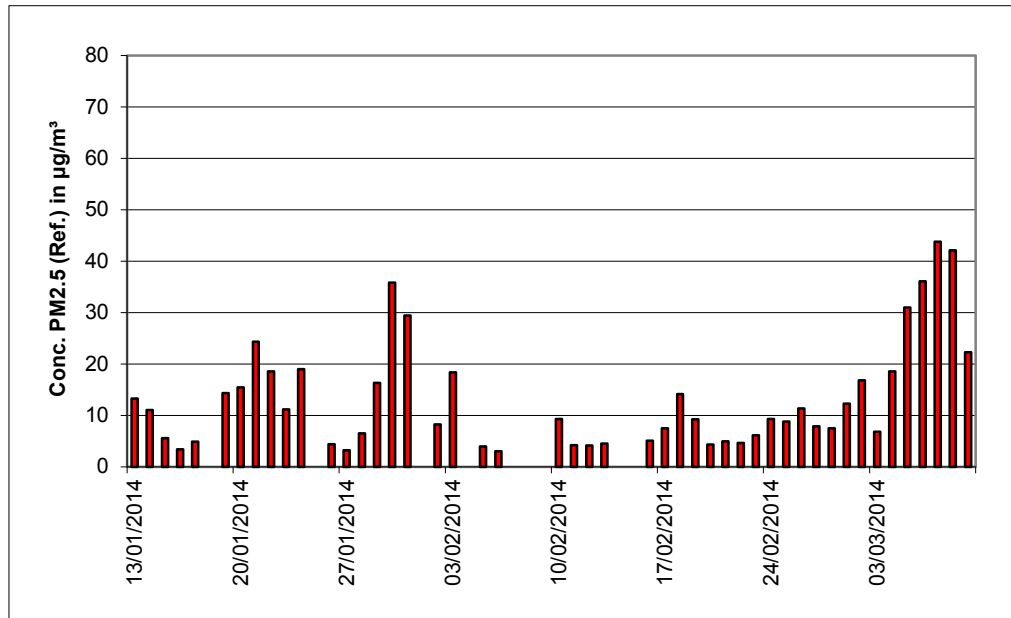


Figure 20: Course of PM_{2.5} concentrations (reference) at test site "Cologne, winter 2014"

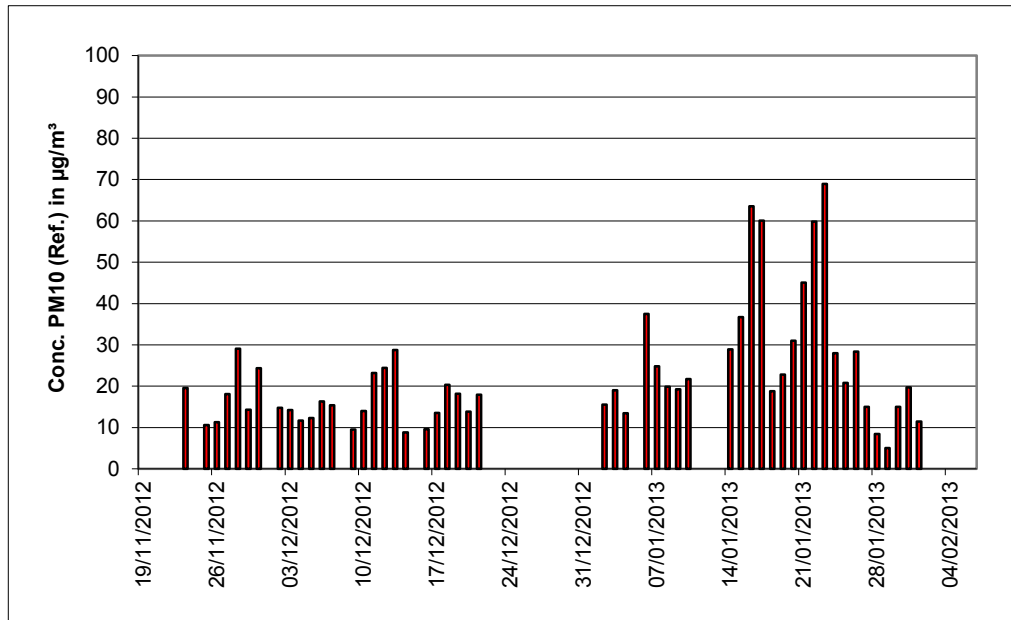


Figure 21: Course of PM₁₀ concentrations (reference) at test site "Cologne, winter"

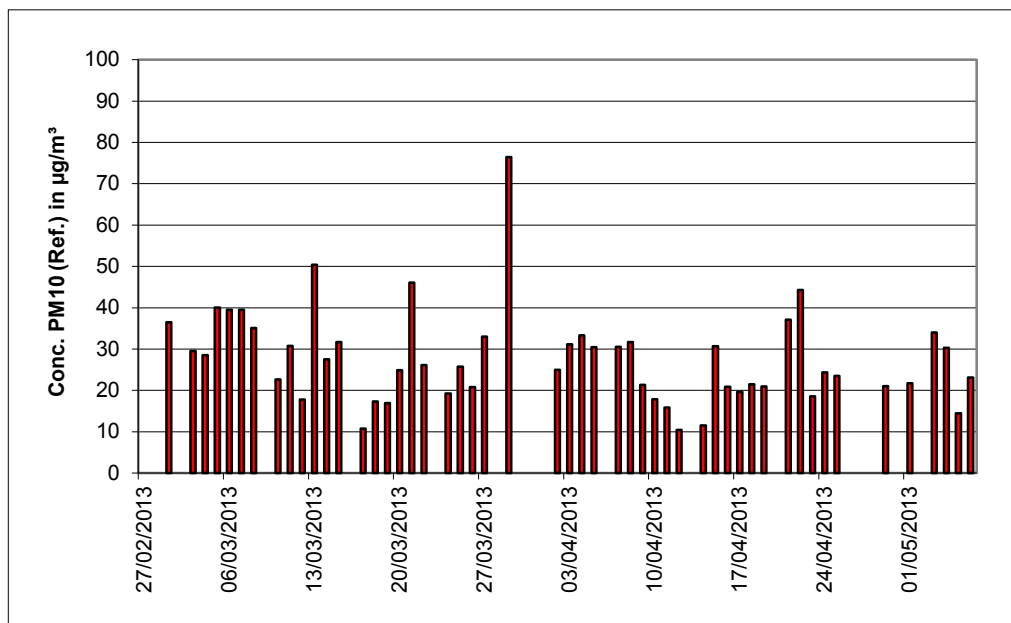


Figure 22: Course of PM₁₀ concentrations (reference) at test site "Bonn, winter"

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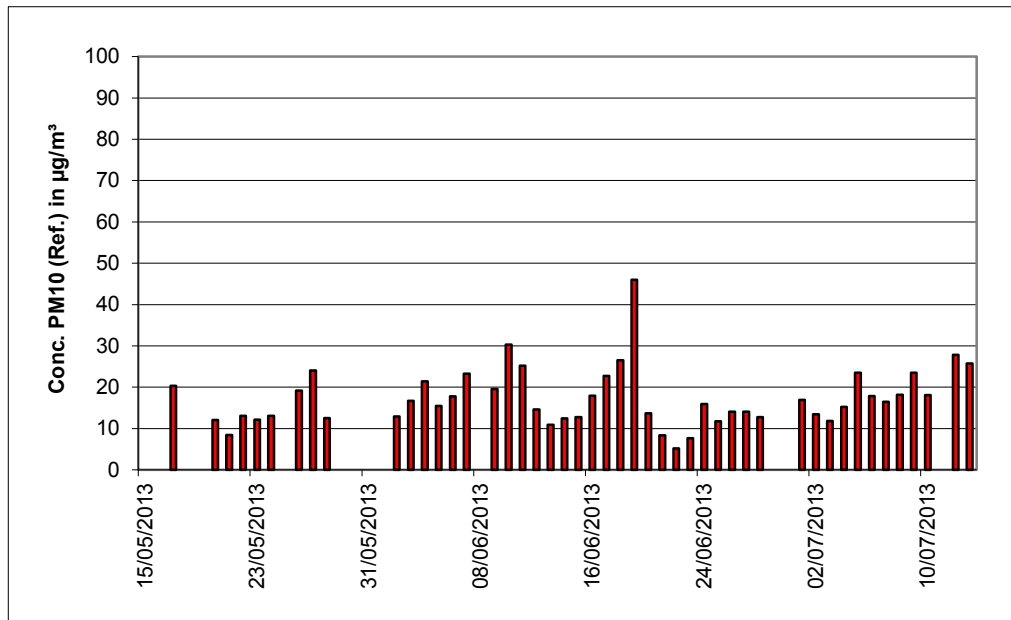


Figure 23: Course of PM₁₀ concentrations (reference) at test site "Cologne, summer"

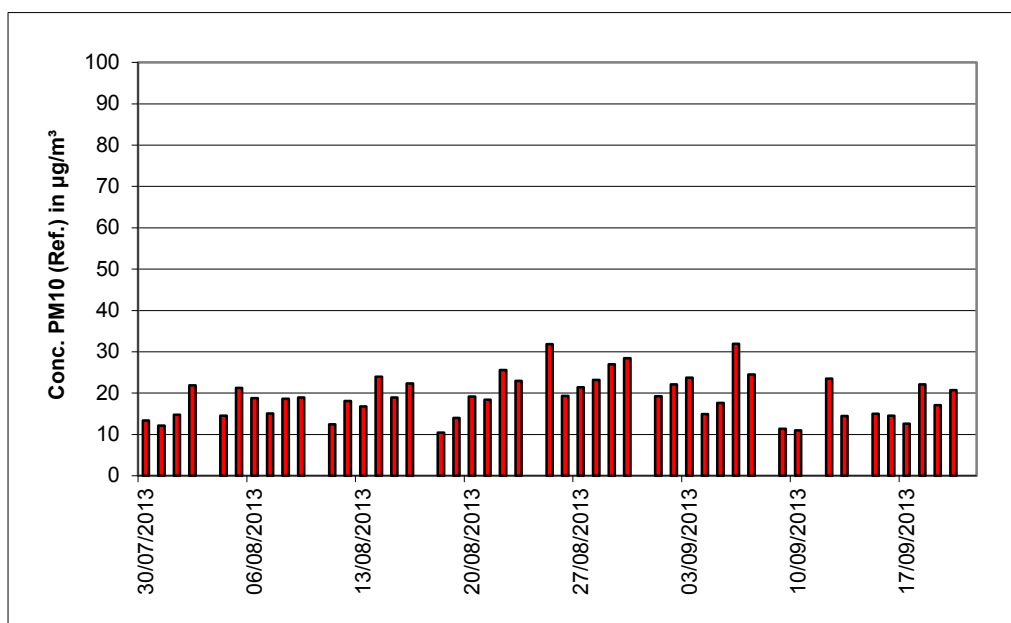


Figure 24: Course of PM₁₀ concentrations (reference) at test site "Rodenkirchen, summer"

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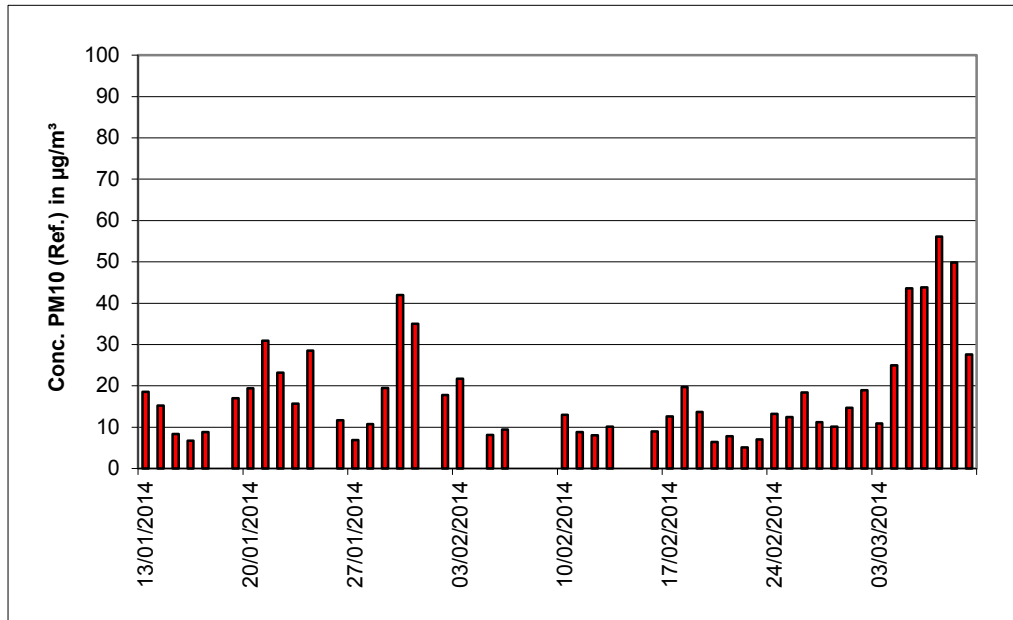


Figure 25: Course of PM₁₀ concentrations (reference) at test site "Cologne, winter 2014"

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The following figures show the measuring cabinet at the field test sites Cologne, Bonn and Rodenkirchen.



Figure 26: Field test site Cologne, summer & winter



Figure 27: Field test site Bonn, winter

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Figure 28: Field test site Rodenkirchen, summer

In addition to the measuring systems for the measurement of ambient air pollution through suspended particulate matter, a data acquisition system for meteorological parameters was installed on the cabinet/at the test site where the measurement was carried out. Ambient temperature, ambient pressure, humidity, wind velocity, wind direction, and the amount of precipitation were monitored continuously. 30-minutes mean values were stored.

The cabinet setup and the arrangement of the sample probes had the following dimensions:

- | | |
|--|------------------------------------|
| • Height of cabinet roof: | 2.50 m |
| • Sampling height for tested system | 0.96 m / 0.51 m above cabinet roof |
| • Sampling height for reference system | 3.46 / 3.01 m above ground |
| • Height of wind vane: | 4.5 m above ground |

The following Table 7 therefore contains an overview of the most important meteorological parameters that have been obtained during the measurements at the 4 field test sites (+ validation campaign Cologne, winter 2014) as well as an overview of the concentrations of suspended particulate matter during the test period. All single values are provided in annexes 5 and 6.

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Table 7: *Ambient conditions at the field test sites, daily mean values*

	Cologne, winter	Bonn, winter	Cologne, summer	Rodenkirchen, summer	Cologne, winter 2014*
Number of value pairs Reference PM ₁₀	52	51	47	45	46
Number of value pairs Reference PM _{2.5}	52	51	46	45	47
PM_{2.5} ratio in PM₁₀ [%]					
Range	41.6 – 97.2	42.2 – 96.5	42.5 – 84.1	38.8 – 73.6	32.0 – 90.9
Mean value	73.8	70.5	62.2	54.0	68.5
Ambient temperature [°C]					
Range	-3.3 – 11.9	-3.4 – 20.0	6.3 – 28.2	9.9 – 27.8	2.5 – 13.1
Mean value	4.6	7.9	16.7	17.2	6.5
Ambient pressure [hPa]					
Range	988 – 1027	985 – 1021	993 – 1021	988 – 1016	984 – 1022
Mean value	1004	1004	1008	1005	1000
Rel. humidity [%]					
Range	70.0 – 91.2	42.8 – 85.8	51.4 – 89.5	48.6 – 96.4	46.8 – 87.2
Mean value	81.2	63.2	68.4	75.6	74.4
Wind velocity [m/s]					
Range	0.0 – 3.3	0.4 – 4.2	0.1 – 2.7	1.2 – 5.0	0.0 – 3.0
Mean value	0.9	1.6	0.8	2.6	0.0
Amount of precipitation [mm/d]					
Range	0.0 – 25.7	0.0 – 13.2	0.0 – 32.4	0.0 – 21.3	0.0 – 18.9
Mean value	2.9	0.9	3.7	1.9	1.7

* Validation campaign for software 3.0.1, refer to chapter 7 Investigations for the validation of the instrument software 3.0.1 on page 194

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Sampling duration

According to Standard EN 12341, the sampling time shall be 24 h. However, for low concentrations longer sampling times are permissible while for high concentrations shorter sampling times are allowed as well.

According to Standard EN 14907, the sampling time shall be 24 h ± 1 h.

During the field test, a sampling time of 24 h was set for all devices (10:00 – 10:00 (Cologne) and 7:00 – 7:00 (Bonn) and 9:00 – 9:00 (Rodenkirchen)).

Data handling

Before the respective analyses for each test site were carried out, the paired reference values determined during the field test were subject to a statistical outlier test according to Grubbs (99 %) in order to prevent any effects of evidently implausible data on the test results. Value pairs identified as significant outliers may be discarded from the pool of values as long as the critical value of test statistic does not fall below the target. According to the Guide [5] of January 2010, not more than 2.5 % of data pairs shall be determined as outliers and discarded.

As far as candidates are concerned, the measured values are usually not discarded unless there are proven technical reasons for implausible values. Throughout the testing no values measured by the candidates were discarded.

Table 8 and Table 9 provide an overview of the number of value pairs that were identified as significant outliers and therefore removed at each site (reference).

The following value pairs were discarded:

Table 8: Results of the Grubbs' outlier test – reference PM₁₀

Test site	Date	Reference 1 [µg/m³]	Reference 2 [µg/m³]
Cologne, summer	11.07.2013	31.0	28.1

Table 9: Results of the Grubbs' outlier test – reference PM_{2.5}

Test site	Date	Reference 1 [µg/m³]	Reference 2 [µg/m³]
Cologne, summer	05.07.2013	14.6	17.4

Filter handling– mass determination

The following filters were used in the performance test:

Table 10: Used filter materials

Measuring system	Filter material, type	Manufacturer
Reference systems LVS3	Emfab™, Ø 47 mm	Pall

The filters were handled in compliance with Standard EN 14907.

Details on filter handling and weighing processes are describes in annex 2 of this report.

5. Reference measurement method

In accordance with Standards EN 12341 and EN 14907, the following devices were used in the testing:

1. as reference device for PM₁₀: Small Filter Device Low Volume Sampler LVS3
Manufacturer: Ingenieurbüro Sven Leckel,
Leberstraße 63, Berlin, Germany
Date of construction: 2007
PM₁₀ sampling head
2. as reference device for PM_{2.5}: Small Filter Device Low Volume Sampler LVS3
Manufacturer: Ingenieurbüro Sven Leckel,
Leberstraße 63, Berlin, Deutschland
Date of construction: 2007 and 2010
PM_{2.5} sampling head

During the testing, two reference systems for each PM₁₀ and PM_{2.5} were operated simultaneously with a flow rate of 2.3 m³/h. Under real operating conditions the volume flow control accuracy is < 1 % of the nominal flow rate.

The sampling head of the small filter device LVS3 sucks in the sample air via a rotary vane vacuum pump. The sample volume flow is then measured by means of a measuring orifice between filter and vacuum pump. The suctioned air then streams out of the pump via a separator for the abrasion of the rotary vanes and towards the air outlet.

As soon as the sampling is complete the electronic measurement equipment displays the sucked-in sample air volume in standard or operating m³.

The PM₁₀ and PM_{2.5} concentrations were determined by dividing the amount of suspended particulate matter on each filter that had been determined gravimetrically in the laboratory by the respective sampling volume in operating m³.

6. Test results

6.1 4.1.1 Measured value display

The AMS shall have a means to display the measured values.

6.2 Equipment

Additional equipment is not required.

6.3 Method

It was checked whether the AMS has a means to display the measured values.

6.4 Evaluation

The measuring system provides a display that shows the measured values. During measurement mode, the currently measured PM_x-concentration (respectively during the purge mode the measured voltage value in mV) is shown at the right hand side of the display. On the left hand side the following measured values are shown:

PM2.5 avg:	Mean value of the measured mass concentration PM _{2.5} (moving, updated every second)
PM10 avg:	Mean value of the measured mass concentration PM ₁₀ (moving, updated every second)
Fl.Offset:	Photometer-Offset, determined during zero air purging
Phototemp:	Photometer temperature
Ext.temp:	Ambient temperature
Humidity:	Ambient relative humidity
Pressure:	Ambient pressure

6.5 Assessment

The measuring system provides a display that shows the measured values.

Performance criterion met? yes

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6.6 Detailed presentation of test results

Figure 29 shows the user interface with the current concentrations.

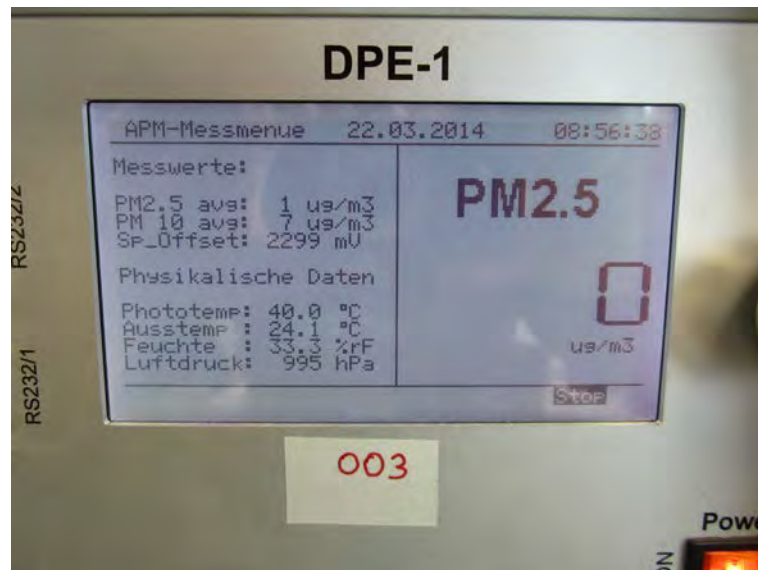


Figure 29: Display of measured concentrations (here: PM_{2.5}, German language setup)

6.1 4.1.2 Easy maintenance

Necessary maintenance of the measuring systems should be possible without larger effort, if possible from outside.

6.2 Equipment

Additional equipment is not required.

6.3 Method

Necessary regular maintenance work was carried out according to the instructions given in the manual.

6.4 Evaluation

The operator shall carry out the following maintenance work:

1. Check of system status.
The system status can be monitored and controlled directly or online.
2. The sampling inlet has to be cleaned in general according to the instructions provided by the manufacturer, at which the local PM conditions have to be considered (during the type approval test approx. every 4 weeks).
3. A check of the sensors for ambient temperature and ambient pressure should be carried out every 3 months according to EN TS 16450 [9].
4. A check of the flow rate should be carried out every 3 months according to EN TS 16450 [9].
5. In the context of the check of the flow rate, a check on tightness should also be carried out every 3 months.
6. The virtual impactor has to be cleaned latest every 3 months.
7. According to the manufacturer, the internal filters in the device (zero air filter, outlet filter for photometer, bypass filter and pump outlet filter) shall be exchanged latest every 6 months.
8. The photometer should be sent to the manufacturer for re-calibration at least once a year.

According to the manufacturer, the photometer has to be completely replaced, if:

- the completely collected PM mass exceeds 50 mg (correspond to approx. 200 days with an average concentration of 50 µg/m³)
- the photometer offset exceeds 2500 mV.

After the annual maintenance of the photometer, the measuring system is to be calibrated at the measurement site with the gravimetric PM₁₀-reference method according to EN 12341 respectively with the gravimetric PM_{2.5}-reference method according to EN 14907. Preferably a seasonal calibration rhythm is to follow.

9. During the annual basic maintenance the cleaning of the sampling tube has also to be considered.
10. The vacuum pump has a life time of approx. 2 years – after reaching the lifetime, the pump must be completely replaced. Failure of the pump is displayed on the system with an error message

Maintenance work shall be carried out according to the instructions provided in the manual (chapter 10). In general, all work can be carried out with commonly available tools.

6.5 Assessment

Maintenance work can be carried out from the outside with commonly available tools and reasonable time and effort. The operations described in item 6ff shall only be performed when the device is on standstill. These works occur every 3 months (cleaning of virtual impactor), every 6 months (filter replacement), once a year (photometer) respectively every 2 years (pump). In the meantime, maintenance work is limited to the check of contaminations, plausibility and possible status/error messages.

Performance criterion met? yes

6.6 Detailed presentation of test results

During the testing, work on the devices was carried out on the basis of operations and work processes described in the manuals. However, there was no replacement of the photometer. By adhering to the described procedures no difficulties were observed. Up to this point, all maintenance could be carried out without difficulty and with conventional tools.

6.1 4.1.3 Functional check

If the operation or the functional check of the measuring system requires particular instruments, they shall be considered as part of the measuring system and be applied in the corresponding sub-tests and included in the assessment.

Test gas units included in the measuring system shall indicate their operational readiness to the measuring system by a status signal and shall provide direct as well as remote control via the measuring system.

6.2 Technical equipment

Operator's manual, zero filter, test gas box (optional).

6.3 Method

The system status is monitored continuously and problems are indicated by a series of different status messages. The current status of the monitored parameters can be viewed directly on the instrument display or they can be taken from the data record. If there is an error message, the message is shown in the display permanently.

The zero point of the measuring system can also be checked externally by applying a zero filter to the instrument's inlet. The use of this filter allows the provision of particulate-free air.

During the testing, the zero point was determined using a zero filter approx. every 4 weeks.

For external check of the sensitivity of the photometer, the instrument manufacturer has developed the following test method:

By offering propane to the photometer, a scattered light signal in the range of 300 - 400 mV (corresponds to an aerosol concentration of approx. 70 µg/m³) is induced. The stability of that signal is taken as a measure for the stability of the sensitivity. During an investigation on the repeatability, a standard deviation smaller than 1 % of the mean of the measured values could be determined in 15 measurements (refer to Table 11), so that the test method itself is to be considered sufficiently stable and reproducible.

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Table 11: *Test on repeatability with test gas box*

Measurement	Time	Measured value [mV]
1	8:48	363
2	8:54	366
3	9:02	370
4	9:09	370
5	9:16	369
6	9:28	368
7	9:33	364
8	9:40	367
9	9:48	365
10	9:57	369
11	10:05	363
12	10:14	372
13	10:22	373
14	10:30	364
15	10:37	370
No. of values		15
Mean value		367.53
Standard deviation s_{x0}		3.25
Detection limit X [% of mean value]		1.90

Unfortunately the test method was not available before December 2013, so that the necessary tests at the reference point in the lab (climate chamber, mains voltage) could be carried out, but there are no long term drift investigations at the reference point available from the field test. As the devices have shown no drift effects during the permanent comparison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely abstain from this test point in future for type approval testing according to EN TS 16450 [9].

6.4 Evaluation

All functions described in the operator's manual are available or can be activated. The current instrument status is continuously monitored and different warning messages are displayed in the case of problems.

External zero point checks by means of a zero filter can be carried out at any time.

An external check of the sensitivity of the photometer can also be carried out at any time with the help of the test gas check, however it could not be verified during the field test campaigns within the context of the type approval test. During an investigation on the repeatability, a standard deviation smaller than 1 % of the mean of the measured values could be determined in 15 measurements, so that the test method itself is to be considered sufficiently stable and reproducible and in general suitable for a stability check of the measuring system.

6.5 Assessment

All functions described in the operator's manual are available, can be activated, and work properly. The current instrument status is continuously monitored and different warning messages are displayed in the case of problems.

The results of the external zero point checks by means of zero filter that were carried out during the field tests are described in Chapter 6.1 5.3.12 Long-term drift in this report.

An external check of the sensitivity of the photometer can also be carried out at any time with the help of the test gas check, however it could not be verified during the field test campaigns within the context of the type approval test. During an investigation on the repeatability, a standard deviation smaller than 1 % of the mean of the measured values could be determined in 15 measurements, so that the test method itself is to be considered sufficiently stable and reproducible and in general suitable for a stability check of the measuring system.

Performance criterion met? yes

6.6 Detailed presentation of test results

See chapter 6.1 5.3.12 Long-term drift

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6.1 4.1.4 Setup times and warm-up times

The AMS' setup and warm-up times shall be stated in the manual.

6.2 Equipment

A timer was provided additionally.

6.3 Method

The measuring systems were activated according to the manufacturer's specifications. The amounts of time required for setup and warm-up were recorded separately.

Structural measures taken before installation, like for instance the set-up of the power supply line or necessary measures for protection of the measuring system, have not been assessed here.

6.4 Evaluation

The setup time comprises the time needed for all necessary works from system installation to start-up.

The APM-2 measuring system is equipped with weatherproof housing and thus designed for outdoor installation. As a result, all that is needed at the installation site is a 220V power connection.

The following steps are required for the (initial) installation of the measuring system:

- Unpacking and Installation of the AMS
- Installation of sampling tube, impactor inlet and ambient sensor
- Power connection
- Power-up of AMS
- After a warm-up period of at least 1 h (photometer temperature has to be at 40°C:
 - Test on tightness
 - Check of ambient sensor
 - Check of volume flow
 - (optional) Check with test gas
- Optional connection of peripheral logging systems (RS232) to the corresponding port

These operations, and therefore the setup time for the first-time installation, require approx. 1-2 h. If mounted once, the measuring system is easy to transport as a whole and can be moved from one measuring test site to another.

The warm-up time is the time between the start of operation of the measuring system and the point when it is ready for measurement.

Upon power-up of the system, the measurement can be started directly by selecting the menu-point "Measurement" after the nominal temperature of the photometer has been reached. The measurement starts with two minutes of purging the photometer with zero air and following zero point adjustment. This zero point purging is carried out automatically for a time period of two minutes during measurement operation. The measurement itself starts immediately after the first purging. After that, the measuring systems carries out – dependent on the switching interval (during the type approval test every 2 min) – alternately the PM_{2.5} respectively PM₁₀-measurements. The warm-up time is thus in normal case at least 15-30 min – depending on the time needed to reach the nominal temperature of the photometer.

If necessary, any changes to basic parameters can quickly be carried out in a few minutes by personnel that are familiar with the AMS. However, normal measuring operation is interrupted for this.

6.5 Assessment

Setup and warm-up times were determined.

The measuring system can easily be operated at various measuring sites. The setup time amounts to approximately 1-2 h at first-time installation. The warm-up time amounts to 15-30 min, depending on the necessary stabilization time.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

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6.1 4.1.5 Instrument design

The instruction manual shall include specifications of the manufacturer regarding the design of the measuring system. These elements are:

Instrument shape (e.g. bench mounting, rack mounting, free mounting)

mounting position (e.g. horizontal or vertical mounting)

safety requirements

dimensions

weight

power consumption.

6.2 Equipment

Additionally, a measuring device for recording the power consumption and a balance were used to test this performance criterion.

6.3 Method

The supplied instruments were compared to the descriptions in the manuals. The specified power consumption is determined over a 24 h-standard operation during the field test.

6.4 Evaluation

The measuring system APM-2 is equipped with weatherproof housing and thus designed for outdoor installation. The AMS shall be installed in horizontal position.

Dimensions and weight of the AMS match the information given in the operator's manual.

According to the manufacturer, the power consumption of the AMS with the used pump is about 80 W at maximum for the complete system. During a 24 h test the total power demand of the AMS was determined. During this test, the stated value was not exceeded at any time.

6.5 Assessment

The instrument design specifications listed in the operator's manual are complete and correct.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

6.1 4.1.6 Unintended adjustment

It shall be possible to secure the adjustment of the measuring system against illicit or unintended adjustment during operation.

6.2 Technical equipment

No additional tools are required here.

6.3 Method

The measuring system is operated via the control unit with a Jog-Dial on the front of the device.

The menu levels which are not protected by password mostly allow reviewing measurements, parameters etc. respectively carrying out functional checks.

The adjustment of parameters for the measurement is password protected (Menu: Setup/Measurement Parameter). Instrument parameters, which are implemented in the system, can only be accessed by specifically authorized personnel via the menu "Setup/Device Adjustment", which is protected by the factory-password.

Moreover, the door of the weatherproof housing is protected by two locks which prevent unauthorized access to the measuring system.

6.4 Evaluation

Unintended adjustment of instrument parameters can be avoided by password protection. Moreover, additional protection against unauthorized intervention is given by the weatherproof housing with lockable door.

6.5 Assessment

The measuring system is secured against illicit or unintentional adjustments of instrument parameters. Additional protection against unauthorized access is provided by the lockable door of the weatherproof housing.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

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6.1 4.1.7 Data output

The output signals shall be provided digitally (e.g. RS232) and/or as analogue signals (e.g. 4 mA to 20 mA).

6.2 Equipment

PC with "HyperTerminal" software

6.3 Method

The measuring system has got an internal buffer with 3.5 MB capacity. The buffer is designed as a non-volatile ring buffer. Additionally the measured data can be saved directly on a SD-card.

During type approval test, the measured data have been saved device-internally on the SD-card and have been readout. The measuring system also offers the possibility to output measured signals or communicate via serial interface RS232 (serial, Bayern-Hessen protocol). The transfer of measured data via RS 232 to a terminal software is easily possible.

The AMS does not provide analogue output signals.

6.4 Evaluation

The measured signals are offered as follows on the front side of the instrument:

- 1 x SD card for saving measured values
- 1 x RS232 interface for communication via serial interface / Bayern-Hessen-Protocol
- 1 x RS232 interface as programming interface (for service only)

6.5 Assessment

The measured signals are stored on SD-card or offered digitally (via RS232).

Performance criterion met? yes

6.6 Detailed presentation of test results

Figure 30 shows the instrument's front side with the various data outputs.



Figure 30: Front side of the APM-2 (top right side: SD-card slot, left side RS232)

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6.1 5.1 General

The manufacturer's information provided in the operator's manual shall not contradict the findings of the performance test.

6.2 Equipment

Not required here.

6.3 Method

The test results are compared with the information given in the manual.

6.4 Evaluation

Instances where the first draft of the manual deviated from the actual design of the instrument have been corrected.

6.5 Assessment

No differences between the instrument design and the descriptions given in the manuals were found.

Performance criterion met? yes

6.6 Detailed presentation of test result

For this module, refer to item 6.4.

6.1 5.2.1 Certification ranges

The certification range over which the AMS will be tested shall be determined.

6.2 Equipment

No additional tools are required here.

6.3 Method

The certification range over which the AMS will be tested shall be determined.

6.4 Evaluation

VDI Standard 4202, Sheet 1 lists the following minimum requirements for the certification ranges of measuring systems intended for the measurement ambient air pollution through suspended particulate matter:

Table 12: Certification ranges

Component	Minimum value cr	Maximum value cr	Limit value	Assessment period
	in µg/m ³	in µg/m ³	in µg/m ³	
PM ₁₀	0	100	50	24h
PM _{2,5}	0	50	25	Calendar year

Certification ranges are related to the limit value with the shortest assessment period and used for the assessment period of the measuring system in the range of the limit value. This assessment of the measuring system in the range of the limit value is performed as part of the determination of the expanded uncertainty of the candidates according to the guide [5]. For this purpose, the following values are used as reference values in accordance with the specifications of the Guide:

PM₁₀: 50 µg/m³

PM_{2,5}: 30 µg/m³

Refer to test item 6.1 5.4.10 Calculation of expanded uncertainty between systems under test in this report.

6.5 Assessment

Assessment of AMS in the range of the relevant limit values is possible.

Performance criterion met? yes

6.6 Detailed presentation of test results

Refer to test item 6.1 5.4.10 Calculation of expanded uncertainty between systems under test in this report.

6.1 5.2.3 Negative output signals

Negative output signals or measured values may not be suppresses (life zero).

6.2 Equipment

No additional tools are required here.

6.3 Method

In the field test and during laboratory testing, it was examined whether the AMS has a means to output negative measured values as well.

6.4 Evaluation

The measuring system can output negative values both via the display and via the data outputs, though no negative output signals occurred during performance testing. Due to measuring principle and instrument design, negative output signals are not to be expected.

6.5 Assessment

Negative output signals are directly displayed by the AMS and can be output via corresponding data outputs. Yet, they are not to be expected due to measuring principle and instrument design.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

6.1 5.2.4 Failure in the mains voltage

In case of malfunction of the measuring system or failure in the mains voltage for a period of up to 72 h, uncontrolled emission of operation and calibration gas shall be avoided. The instrument parameters shall be secured by buffering against loss caused by failure in the mains voltage. When mains voltage returns, the instrument shall automatically reach the operation mode and start the measurement according to the operating instructions.

6.2 Equipment

Not required here.

6.3 Method

A failure in the mains voltage was simulated and it was tested, whether the AMS remains undamaged and is ready for measurement after the restart of power supply.

6.4 Evaluation

The measuring systems do not require operation gas or calibration gas, therefore uncontrolled emission of gases is not possible.

When mains voltage returns after a power failure, the AMS automatically returns to the measuring mode after re-stabilization of the photometer temperature and two-minutes zero air purging (see also item 6.1 4.1.4 Setup times and warm-up times).

6.5 Assessment

All parameters are secured against loss by buffering. When mains voltage returns the AMS returns to failure-free operation mode and automatically resumes measuring after re-stabilization of the photometer temperature and two-minutes zero air purging.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

6.1 5.2.5 Operating states

The measuring system shall allow control of important operating states by telemetrically transmitted status signals.

6.2 Equipment

PC for data acquisition.

6.3 Method

A PC was connected locally via RS232 to the measuring system to check data transfer and instrument status.

The use of corresponding routers or modems enables tele monitoring.

6.4 Evaluation

The AMS allows telemetric monitoring and control via various ports (Ethernet, RS232).

6.5 Assessment

The measuring systems can be monitored and operated extensively from an external PC via modem or router.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

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6.1 5.2.6 Switch-over

Switch-over between measurement and functional check and/or calibration shall be possible telemetrically by computer control or manual intervention.

6.2 Equipment

Not required here.

6.3 Method

The operator can monitor the AMS directly or via remote control. A telemetric control is not yet implemented.

6.4 Evaluation

All operating procedures that do not require practical work on site can be monitored by the user directly or via telemetric remote control. A telemetric control is not yet implemented.

6.5 Assessment

The measuring system can be monitored by the user directly or via remote control. A telemetric control is not yet implemented, but already planned for the future.

Performance criterion met? no

6.6 Detailed presentation of test results

Not required here.

6.1 5.2.7 Maintenance interval

The maintenance interval of the measuring system shall be determined during the field test and specified. The maintenance interval should be three months, if possible, but at least two weeks.

6.2 Equipment

Not required here.

6.3 Method

The types of maintenance and the maintenance intervals required to ensure proper functioning of the AMS were determined in this performance criterion. In order to determine the maintenance interval, the results of the determination of the drift at zero point according to chapter 6.1 5.3.12 Long-term drift have been taken into account.

6.4 Evaluation

During the entire field test no impermissible drifts at zero have been observed in the candidates.

An external check of the sensitivity of the photometer is possible with the help of the test gas procedure, but could not be checked in the field test campaign during the type approval test. During an investigation on the repeatability, a standard deviation smaller than 1 % of the mean of the measured values could be determined in 15 measurements, so that the test method itself is to be considered sufficiently stable and reproducible and in general suitable for the stability check of the measuring system. As the devices have shown no drift effects during the permanent comparison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely abstain from this test point in future for type approval testing according to EN TS 16450 [9].

Thus, the maintenance interval is determined by regularly necessary maintenance work (see also module 4.1.2).

During operating time, maintenance may be limited to contamination checks, plausibility checks and possible status and error messages.

6.5 Assessment

The maintenance interval of 4 weeks has been determined by regular maintenance work.

Performance criterion met? yes

6.6 Detailed presentation of results

For necessary maintenance work refer to item (module) 4.1.2 in this report or chapter 10 in the operator's manual.

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6.1 5.2.8 Availability

The availability of the measuring system shall be determined during the field test and shall be at least 95 %.

6.2 Equipment

Not required here.

6.3 Method

The start and end point of the availability checks are determined by the start and end point at each of the field test sites. For this purpose, all interruptions, for instance those caused by malfunctioning or maintenance work, are recorded as well.

6.4 Evaluation

Table 13 and Table 14 provide lists of operation times, time used for maintenance, and malfunction times. The measuring systems were operated over a period of 264 days in total during the field test (4 comparison campaigns). This period includes 22 days of zero filter operation respectively device audits during the type approval test (see also annex 5).

Downtimes caused by external influences which the instrument cannot be blamed for have been recorded on 31 December 2012 and 01 January 2013 (failure in the mains voltage). As a consequence of these external influences, the total operation time has been reduced to 262 days.

The following instrument malfunctions have been recorded:

SN3:

There have been none instrument malfunctions.

SN4:

Between 24 May 2013 and 26 May 2013 there has been no data recording due to unknown reasons for SN4 – thus there have been three days of downtime.

Apart from that no further instrument malfunctions were recorded.

Downtimes caused by maintenance of the sampling heads, regular checks of flow rates (respectively tightness) amount to 0.5 to 1 h per system. Daily mean values affected by this have not been discarded.

6.5 Assessment

The availability was 100 % for SN3 and 98.9 % for SN4 without test-related downtimes. Including test-related downtimes it was 91.6 % for SN3 and 90.5 % for SN4.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 13: Determination of availability (without test-related downtimes)

		System 1 (SN3)	System 2 (SN4)
Operating time	d	262	262
Downtime	d	0	3
Maintenance	d	0	0
Actual operating time	d	262	259
Availability	%	100	98.9

Table 14: Determination of availability (incl. test-related downtimes)

		System 1 (SN3)	System 2 (SN4)
Operating time	d	262	262
Downtime	d	0	3
Maintenance incl. zero filter	d	22	22
Actual operating time	d	240	237
Availability	%	91.6	90.5

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6.1 5.2.9 Instrument software

The version of the instrument software to be tested shall be displayed during switch-on of the measuring system. The test institute shall be informed on changes in the instrument software, which have influence on the performance of the measuring system.

6.2 Equipment

Not required here.

6.3 Method

It was checked whether the measuring system has a means of displaying the instrument software. The manufacturer was advised to inform the test institute on any changes in the instrument software.

6.4 Evaluation

The current software version is displayed in the main menu as well as under menu point "Setup/System info".

The test was started in the year 2012 with software version 1.3. During the test work, the software was constantly developed and optimized, especially for the implementation of the test gas measurement.

With start of the field test in November 2012, the software version 2.1.0 was installed, updated to version 2.3.1 in February 2013 before the campaign „Bonn, winter“ and updated again to version 2.5.2 in June 2013 before the campaign „Cologne, summer“. This version was kept over the complete remaining field test (Cologne, summer and Rodenkirchen).

All implemented modification until version 2.5.2 are related in first line to the implementation of the test gas measurement and have no impact on the performance of the measuring system (refer to Table 5).

For the outstanding lab investigations at the reference point, the software version 3.0.0.d. respectively 3.0.1 was finally made available in December 2013 respectively January 2014.

These software versions contain an optimization of the calculation algorithm by introducing a linearity correction for the measured PM values. As this modification has an impact on the formation of measured values, the following measures for qualification of the new software – in addition to the outstanding lab investigations – have been agreed upon:

All available measured values of the four past comparison campaigns have been recalculated manually with the new calculation algorithm and evaluated again. The results of these investigations can be found in chapter 6.1 5.4.10 Calculation of expanded uncertainty between systems under test.

Furthermore an additional comparison campaign at the test site Cologne, parking lot has been conducted with two candidates and the new software version (Version 3.0.1) for qualification. For this the following test program was carried out in detail:

- Performance of a comparison campaign with at minimum 40 valid data pairs reference vs. candidate
- Determination of the in-between uncertainty for the candidates u_{bs} according to the Guide
- Calculation of the expanded uncertainty of the candidates according to the Guide

- Application of the correction factors and terms determined in chapter 6.1 5.4.11
Application of correction factors and terms
- Re-calculation of the equivalence for the 4 data sets of the type approval at hand + additional data set from the validation campaign „Cologne, winter 2014“ according to the approach of chapter „8.2 Suitability test“ of EN/TS 16450 [9]

The results of the additional tests can be found in chapter 7 Investigations for the validation of the instrument software 3.0.1.

An overview on the implemented modifications since start of the test work can be found in chapter 4.1 General.

The reliability of operation of the measuring system is increased continuously by the modifications. No significant impact on the instrument performance is to be expected for the changes up to version 3.0.0.b. The implemented modification in the calculation algorithm since version 3.0.0.b has been validated through an extensive test program (refer to chapter 7 starting with page 194 in this report).

6.5 Assessment

The version of the instrument software is shown in the display. The test institute is informed on any changes in the instrument software.

Performance criterion met? yes

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6.6 Detailed presentation of test results



Figure 31: Display of software version 3.0.1

6.1 5.3.1 General

The testing is performed on the basis of the minimum requirements stated in VDI Standard 4202, Sheet 1 (September 2010).

6.2 Equipment

Not required here.

6.3 Method

The testing is performed on the basis of the minimum requirements stated in VDI Standard 4202, Sheet 1 (September 2010).

6.4 Evaluation

After extensive revision, the VDI Standards 4202, Sheet 1 and 4203, Sheet 3 has been newly published in September 2010. Unfortunately, after this revision there are several ambiguities and inconsistencies in relation to concrete minimum requirements and the general significance of particular test items as far as the testing of particulate measuring systems is concerned. The following test items are in need of clarification:

6.1 5.3.2 Repeatability standard deviation at zero point

→ no performance criterion defined

6.1 5.3.3 Repeatability standard deviation at reference point

→ not applicable to particulate measuring devices

6.1 5.3.4 Linearity (lack of fit)

→ not applicable to particulate measuring devices

6.1 5.3.7 Sensitivity coefficient of surrounding temperature

→ no performance criterion defined

6.1 5.3.8 Sensitivity coefficient of supply voltage

→ no performance criterion defined

6.1 5.3.11 Standard deviation from paired measurements

→ no performance criterion defined

6.1 5.3.12 Long-term drift

→ no performance criterion defined

6.1 5.3.13 Short-term drift

→ not applicable to particulate measuring devices

6.1 5.3.18 Overall uncertainty

→ not applicable to particulate measuring devices

For this reason, an official enquiry was made to the relevant body in Germany, to define a coordinated procedure for dealing with the inconsistencies in the guideline.

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The following procedure was suggested:

The test items 5.3.2, 5.3.7, 5.3.8, 5.3.11, and 5.3.12 are evaluated as before on the basis of the minimum requirements stated in the 2002 version of VDI Standard 4202, Sheet 1 (i.e. applying the reference values B₀, B₁, and B₂).

The test items 5.3.3, 5.3.4, 5.3.13, and 5.3.18 are omitted as they are irrelevant to particulate measuring devices.

The relevant body in Germany agreed with the suggested procedure by decisions of 27 June 2011 and 07 October 2011.

6.5 Assessment

The test was carried out on the basis of the performance criteria stated in VDI Standard 4202, Sheet 1 (September 2010). However, the test items 5.3.2, 5.3.7, 5.3.8, 5.3.11, and 5.3.12 were evaluated on the basis of the performance criteria stated in the 2002 version of VDI Standard 4202, Sheet 1 (i.e. applying the reference values B₀, B₁, and B₂). The test items 5.3.3, 5.3.4, 5.3.13, and 5.3.18 were omitted as they are irrelevant to particulate measuring devices.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

6.1 5.3.2 Repeatability standard deviation at zero point

The repeatability standard deviation at zero point shall not exceed the requirements of Table 2 in VDI Standard 4202, Sheet 1 (September 2010) in the certification range according to Table 1 in VDI Standard 4202, Sheet 1 (September 2010).

In case of deviating certification ranges, the repeatability standard deviation at zero point shall not exceed 2 % of the upper limit of this certification range.

Note:

With regard to dust measuring devices, this test item cannot be evaluated on the basis of the current version of VDI Standards 4202, Sheet 1 (September 2010) and 4203, Sheet 3 (September 2010). By resolution of the relevant body in Germany (see module 5.3.1), reference is made to the following minimum requirement in the previous version of this guideline (VDI Standard 4202, Sheet 1; June 2002):

The detection limit of the measuring system shall not exceed the reference value B_0 . The detection limit shall be determined during the field test.

6.2 Equipment

Zero filter for testing the zero point.

6.3 Method

The detection limits of the candidates, SN3 and SN4, were determined by means of zero filters which were installed at the inlets of instruments. Over a period of 15 days and 24 h/day, particulate-free sample air was fed into the systems. The detection limit was determined in the laboratory test because long-term provision of particulate-free air proved impossible under field conditions.

6.4 Evaluation

The detection limit X is calculated from the standard deviation s_{x0} from the measured values when particulate-free sample air is sucked in by the two candidates. It corresponds to the standard deviation from the mean value s_{x0} of the measured values x_{0i} for each candidate multiplied by the Student's factor:

$$X = t_{n-1;0.95} \cdot s_{x0} \quad \text{with } s_{x0} = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1,n} (x_{0i} - \bar{x}_0)^2}$$

Reference value: $B_0 = 2 \mu\text{g}/\text{m}^3$

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6.5 Assessment

The tests resulted in detection limits of 0.03 µg/m³ (PM₁₀) and <0.01 µg/m³ (PM_{2.5}) for System 1 (SN3), and 0.09 µg/m³ (PM₁₀) and 0.10 µg/m³ (PM_{2.5}) for System 2 (SN4).

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 15: *Detection limit PM₁₀*

		SN 3	SN 4
No. of values n		15	15
Mean of zero values	µg/m ³	0.00	0.04
Standard deviation of values	µg/m ³	0.01	0.04
Student-Factor t _{n-1;0,95}		2.14	2.14
Detection limit x	µg/m ³	0.03	0.09

Table 16: *Detection limit PM_{2.5}*

		SN 3	SN 4
No. of values n		15	15
Mean of zero values	µg/m ³	0.00	0.03
Standard deviation of values	µg/m ³	0.00	0.05
Student-Factor t _{n-1;0,95}		2.14	2.14
Detection limit x	µg/m ³	<0,01	0.10

The single measured values used in the determination of the detection limit are given in Annex 1 of this report.

6.1 5.3.3 Repeatability standard deviation at reference point

The repeatability standard deviation at reference point shall not exceed the requirements of Table 2 in VDI Standard 4202, Sheet 1 (September 2010) in the certification range according to Table 1 in VDI Standard 4202, Sheet 1 (September 2010). The limit value or the alert threshold shall be used as reference point.

In case of deviating certification ranges, the repeatability standard deviation at reference point shall not exceed 2 % of the upper limit of this certification range. In this case a value c_t at 70 % to 80 % of the upper limit of this certification range shall be used as reference point.

Note:

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.4 Linearity (lack of fit)

The analytical function describing the relationship between the output signal and the value of the air quality characteristic shall be linear.

Reliable linearity is given, if deviations of the group averages of measured values about the calibration function meet the requirements of Table 2 in VDI Standard 4202, Sheet 1 (September 2010) in the certification range according to Table 1 in VDI Standard 4202, Sheet 1 (September 2010).

For all other certification ranges the group averages of measured values about the calibration function shall not exceed 5 % of the upper limit of the corresponding certification range.

Note:

By resolution of the relevant body in Germany (refer to module 5.3.1), this test item is irrelevant to particulate measuring systems. Particulate measuring systems for PM₁₀ shall be tested according to performance criterion 5.4.2 "Equivalency of the sampling system". Particulate measuring systems for PM_{2.5} shall be tested according to performance criterion 5.4.10 "Calculation of expanded uncertainty between systems under test".

6.2 Equipment

Refer to modules 5.4.2. (PM₁₀) and 5.4.10 (PM_{2.5})

6.3 Method

Particulate measuring systems for PM₁₀ shall be tested according to performance criterion 5.4.2 "Equivalency of the sampling system".

Particulate measuring systems for PM_{2.5} shall be tested according to performance criterion 5.4.10 "Calculation of expanded uncertainty between systems under test".

6.4 Evaluation

Refer to modules 5.4.2. (PM₁₀) and 5.4.10 (PM_{2.5})

6.5 Assessment

Particulate measuring systems for PM₁₀ shall be tested according to performance criterion 5.4.2 "Equivalency of the sampling system".

Particulate measuring systems for PM_{2.5} shall be tested according to performance criterion 5.4.10 "Calculation of expanded uncertainty between systems under test".

Performance criterion met? -

6.6 Detailed presentation of test results

Refer to modules 5.4.2 (PM₁₀) and 5.4.10 (PM_{2.5})

6.1 5.3.5 Sensitivity coefficient of sample gas pressure

The sensitivity coefficient of sample gas pressure at reference point shall not exceed the requirements of Table 2 in VDI Standard 4202, Sheet 1 (September 2010). A value c_t at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

This test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

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6.1 5.3.6 Sensitivity coefficient of sample gas temperature

The sensitivity coefficient of sample gas temperature at reference point shall not exceed the requirements of Table 2 in VDI Standard 4202, Sheet 1 (September 2010). A value c_t at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

This test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.7 Sensitivity coefficient of surrounding temperature

The sensitivity coefficient of surrounding temperature at zero and reference point shall not exceed the requirements of Table 2 in VDI Standard 4202, Sheet 1 (September 2010). A value c_t at 70 % to 80 % of the upper limit of the certification range shall be used at reference point.

Note:

In relation to particulate measuring systems, this test item cannot be evaluated according to the current versions of VDI Standards 4202, Sheet 1 (September 2010) and 4203, Sheet 3 (September 2010), because the minimum requirements are not defined. By resolution of the relevant body in Germany (see module 5.3.1), reference is made to the following requirements stated in the earlier version of VDI Standard 4202, Sheet 1 (June 2002):

If the surrounding temperature changes by 15 K in the range +5 °C to +20 °C or by 20 K in the range +20 °C to +40 °C, the temperature dependence of the measured value at zero point shall not exceed the reference value B_0 .

The temperature dependence of the measured value in the range of the reference value B_1 shall not be greater than ± 5 % of the measured value when a change in temperature by 15 K in the range of +5 °C to +20 °C or +20 °C to +40 °C occurs.

6.2 Equipment

Climatic chamber for a temperature range of -20 to +50 °C, zero filter for testing the zero point, test gas method with propane for testing the reference point.

6.3 Method

According to the manufacturer, the permissible ambient temperature range amounts to -20 °C to +50 °C.

In order to test the dependence of zero point and measured values on the surrounding temperature, the complete measuring systems were operated within a climatic chamber.

For the zero point test particle free sampling air was applied to both measuring systems SN3 and SN4 by means of zero filters installed at the instrument inlets.

For the reference point test, a measured signal was created and evaluated by offering propane to the photometer cell in order to test the stability of the sensitivity of both candidates SN3 and SN4 (test gas method).

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The ambient temperature within the climatic chamber was altered in the sequence

20 °C – -20 °C – 20 °C – 50 °C – 20 °C.

The measured values at zero point (3 x 24 h per temperature level) and the measured values at reference point (3 x per temperature level) were recorded after an equilibration period of 24 h per temperature level.

6.4 Evaluation

Zero point:

The measured concentration values obtained in the individual 24-hour measurements were collected and evaluated. The absolute deviation in µg/m³ per temperature level in relation to the default temperature of 20 °C is considered.

Reference value: $B_0 = 2 \mu\text{g}/\text{m}^3$

Reference point:

The measured value's change in percentage for each temperature level in relation to the initial temperature of 20 °C is checked.

6.5 Assessment

The ambient temperature range tested at the AMS installation site was -20 °C to +50 °C. Looking at the values that were output by the AMS, the maximum dependence of ambient temperature in the range of -20 °C to +50 °C at zero was 0.1 µg/m³ for PM_{2.5} and 0.2 µg/m³ for PM₁₀.

At reference point, no deviations > 2.7 % in relation to the default temperature of 20 °C were observed..

In case of permanent exposition of the device to direct sun radiation combined with very high ambient temperatures (> 35 °C), the instrument manufacturer recommends a sun-protected installation of the device.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 17: *Dependence of zero point on ambient temperature, deviations in µg/m³, mean value of three measurements, PM₁₀, SN3 & SN4*

Ambient temperature		Deviation	
Start temperature	End temperature	SN 3	SN 4
°C	°C	µg/m³	µg/m³
20	-20	0.0	0.2
-20	20	0.0	0.0
20	50	0.0	0.0
50	20	0.0	0.0

Table 18: *Dependence of zero point on ambient temperature, deviations in µg/m³, mean value of three measurements, PM_{2.5}, SN3 & SN4*

Ambient temperature		Deviation	
Start temperature	End temperature	SN 3	SN 4
°C	°C	µg/m³	µg/m³
20	-20	0.0	0.1
-20	20	0.0	0.0
20	50	0.0	0.0
50	20	0.0	0.0

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Table 19: *Dependence of sensitivity (test gas values) on ambient temperature, deviation in %, mean value of three measurements, SN3 & SN4*

Ambient temperature		Deviation	
Start temperature	End temperature	SN 3	SN 4
°C	°C	[%]	[%]
20	-20	-0.4	-1.5
-20	20	2.7	-0.8
20	50	1.7	0.6
50	20	-1.7	-0.4

For the respective results of the 3 individual measurements refer to annex 2 and annex 3.

6.1 5.3.8 Sensitivity coefficient of supply voltage

The sensitivity coefficient of supply voltage shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010). A value c_i at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

In relation to particulate measuring systems, this test item cannot be evaluated according to the current versions of VDI Standards 4202, Sheet 1 (September 2010) and 4203, Sheet 3 (September 2010), because the minimum requirements are not defined. By resolution of the relevant body in Germany (see module 5.3.1), reference is made to the following requirements stated in the earlier version of VDI Standard 4202, Sheet 1 (June 2002):

Change in the measured value at reference value B_1 caused by the common changes in the mains voltage in the interval $(230 +15/-20)$ V shall not exceed B_0 .

6.2 Equipment

Isolation transformer, test gas method with propane for testing the reference point.

6.3 Method

In order to examine the dependence of measured signal on supply voltage, the latter was reduced from 230 V to 210 V and then increased over an intermediate stage of 230 V to 245 V.

For the reference point test, a measured signal was created and evaluated by offering propane to the photometer cell in order to test the stability of the sensitivity of both candidates SN3 and SN4 (test gas method).

As the AMS is not designed for mobile use, separate testing of the dependence of measurement signal on mains frequency was abstained from.

6.4 Evaluation

At reference point, the changes in percentage of the determined measured values were examined for each voltage step in relation to the default voltage of 230 V.

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6.5 Assessment

No deviations > 1.3 % in relation to the default value of 230 V due to changes in supply voltage were detected.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 20 presents a summary of test results.

Table 20: Dependence of measured value on supply voltage, deviation in %, SN3 & SN4

Mains voltage		Deviation	
Start voltage	End voltage	SN 3	SN 4
V	V	[%]	[%]
230	210	0.6	-0.2
210	230	1.2	-0.9
230	245	1.3	-1.3
245	230	1.0	-1.2

For the individual results refer to annex 4 in this report.

6.1 5.3.9 Cross-sensitivity

The change in the measured value caused by interfering components in the sample gas shall not exceed the requirements of Table 2 (VDI Standard 4202, Sheet 1; September 2010) at zero and reference point.

Note:

This test item is irrelevant to particulate measuring systems. As minimum requirement 5.4.5 applies in this case, the test results are stated in module 5.4.5.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

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6.1 5.3.10 Averaging effect

For gaseous components the measuring system shall allow the formation of hourly averages.

The averaging effect shall not exceed the requirements of Table 2 (VDI Standard 4202 Sheet 1; September 2010).

Note:

This test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.11 Standard deviation from paired measurements

The standard deviation from paired measurements under field conditions shall be determined with two identical measuring systems by paired measurements in the field test. It shall not exceed the requirements of Table 2 (VDI Standard 4202, Sheet 1; September 2010).

Note:

In relation to particulate measuring systems, this test item cannot be evaluated according to the current versions of VDI Standards 4202, Sheet 1 (September 2010) and 4203, Sheet 3 (September 2010), because the minimum requirements are not defined. By resolution of the relevant body in Germany (see module 5.3.1), reference is made to the following requirements stated in the earlier version of VDI Standard 4202, Sheet 1 (June 2002):

The "Reproduzierbarkeit" [reproducibility] R_D of the measuring system shall be determined by parallel measurements with two identical measuring systems and shall be at least equal to 10. B_1 shall be used as reference value.

6.2 Equipment

For the determination of reproducibility, the additional measuring systems described in chapter 5 were used.

6.3 Method

Reproducibility is defined as the maximum difference between two randomly chosen single values that have been obtained under equal conditions. Reproducibility was determined using two identical measuring systems that were operated simultaneously during the field test. For this purpose, all measurement data obtained during the entire field test was evaluated.

6.4 Evaluation

The reproducibility is calculated as follows:

$$R = \frac{B_1}{U} \geq 10 \quad \text{with} \quad U = \pm s_D \cdot t_{(n,0.95)} \quad \text{and} \quad s_D = \sqrt{\frac{1}{2n} \cdot \sum_{i=1}^n (x_{1i} - x_{2i})^2}$$

- R = Reproducibility at B_1
- U = Uncertainty
- B_1 = 40 µg/m³ for PM₁₀ and 25 µg/m³ for PM_{2.5}
- s_D = Standard deviation from paired measurements
- n = No. of paired measurements
- $t_{(n,0.95)}$ = Student's factor at confidence level of 95 %
- x_{1i} = Measured signal of system 1 (e.g. SN3) at i^{th} concentration
- x_{2i} = Measured signal of system 2 (e.g. SN4) at i^{th} concentration

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6.5 Assessment

In the field test, the reproducibility for the full dataset was 20 for PM_{2.5} and 16 for PM₁₀.

Performance criterion met? yes

6.6 Detailed presentation of test results

The test results are summarized in Table 21 and Table 22. The graphical representation for PM₁₀ is given in Figure 60 to Figure 64 and for PM_{2.5} in Figure 53 to Figure 57.

Note: The determined uncertainties are related to reference value B₁ for each site:

Table 21: Concentration mean values, standard deviation, uncertainty range, and reproducibility in the field, measured component PM₁₀

Test site	Number	\bar{c} (SN3)	\bar{c} (SN4)	\bar{c}_{ges}	S _D	t	U	R
		µg/m ³	µg/m ³	µg/m ³	µg/m ³		µg/m ³	
Cologne, winter	69	16.8	18.5	17.6	1.335	1.995	2.66	15
Bonn, winter	61	21.9	24.0	23.0	1.667	2.000	3.33	12
Cologne, summer	54	13.8	15.1	14.4	0.943	2.005	1.89	21
Rodenkirchen, summer	53	12.6	12.9	12.8	0.426	2.006	0.85	47
All sites	237	16.5	17.9	17.2	1.256	1.970	2.47	16

Table 22: *Concentration mean values, standard deviation, uncertainty range, and reproducibility in the field, measured component PM_{2.5}*

Site	Number	\bar{c} (SN3)	\bar{c} (SN4)	\bar{c}_{ges}	s _D	t	U	R
		µg/m ³	µg/m ³	µg/m ³	µg/m ³		µg/m ³	
Cologne, winter	69	14.2	14.9	14.5	0.638	1.995	1.27	20
Bonn, winter	61	18.2	19.3	18.8	0.853	2.000	1.71	15
Cologne, summer	54	10.9	11.6	11.2	0.508	2.005	1.02	25
Rodenkirchen, summer	53	9.8	9.5	9.7	0.328	2.006	0.66	38
All sites	237	13.5	14.1	13.8	0.640	1.970	1.26	20

- \bar{c} (SN3): Mean value of concentrations System SN3
- \bar{c} (SN4): Mean value of concentrations System SN4
- \bar{c}_{ges} : Mean value of concentrations Systems SN3 & SN4

For individual values refer to annex 5 of the appendix.

6.1 5.3.12 Long-term drift

The long-term drift at zero point and reference point shall not exceed the requirements of Table 2 (VDI Standard 4202, Sheet 1; September 2010) in the field test. A value c_i at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

In relation to particulate measuring systems, this test item cannot be evaluated according to the current versions of VDI Standards 4202, Sheet 1 (September 2010) and 4203, Sheet 3 (September 2010), because the minimum requirements are not defined. By resolution of the relevant body in Germany (see module 5.3.1), reference is made to the following requirements stated in the earlier version of VDI Standard 4202, Sheet 1 (June 2002):

The temporal change in the measured value at zero concentration shall not exceed the reference value B_0 in 24 h and in the maintenance interval.

The temporal change in the measured value in the range of the reference value B_1 shall not be greater than $\pm 5 \%$ of B_1 in 24 h and in the maintenance interval.

6.2 Equipment

Zero filter for testing the zero point

6.3 Method

The test was carried out as part of the field test over a period of about 10 months altogether (comparison campaigns 1-4) respectively approx. 15 months if considering the validation campaign during winter 2014.

In the context of the regular checks approximately once a month (including those at the beginning and end of tests at each field test site), both measuring systems were operated with zero filters applied to their inlets for at least 24 h. The measured zero values were then evaluated.

For external check of the sensitivity of the photometer, the instrument's manufacturer has developed the following optional test method:

By offering propane to the photometer, a scattered light signal in the range of 300 - 400 mV (corresponds to an aerosol concentration of approx. 70 $\mu\text{g}/\text{m}^3$) is induced. The stability of that signal is taken as a measure for the stability of the sensitivity.

Unfortunately the test method was not available before December 2013, so that the necessary tests at the reference point in the lab (climate chamber, mains voltage) could be carried out, but there are no long term drift investigations at the reference point available from the field test. As the devices have shown no drift effects during the permanent comparison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely abstain from this test point in future for type approval testing according to EN TS 16450 [9].

For quality assurance - according to the manufacturer - the photometer has to be sent once a year to the manufacturer for check and re-calibration. By this, also the requirements on ongoing quality assurance according to chapter 8.4.10 of EN TS 16450 [9] can be accommodated.

6.4 Evaluation

While it is possible to assess zero point drift and drift of the measured value within a 24 h period, it is not useful for particulate measuring systems.

The measuring system carries out a zero point check / adjustment with zero air at the start of a measurement as well as at each hour during operation.

The evaluation at zero point is made on the basis of the measurement results of the regular external zero point measurement by comparing the respective values with the corresponding "measured values" of the previous test and the "measured value" of the first test.

On 31 March 2013 a zero value of 2.7 µg/m³ for PM₁₀ was measured for SN 4 – this value deviates from the start value with 2.7 µg/m³ and is outside of the permissible range of ± 2 µg/m³. A cause for this outlier could not be determined and all corresponding evaluations did not show any exceedance of the permissible limits. There was no externally triggered adjustment of the measuring device.

A regular external check of the sensitivity over the field test period could not be carried out, as suitable test equipment was not available before December 2013. As the devices have shown no drift effects during the permanent comparison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely abstain from this test point in future for type approval testing according to EN TS 16450 [9].

6.5 Assessment

For PM_{2.5}, the maximum deviation at zero point was -1.4 µg/m³ in relation to the previous value and 2.4 µg/m³ in relation to the start value. Thus, it lies within the permissible limits of B₀ = 2 µg/m³.

For PM₁₀, the maximum deviation at zero point was 1.5 µg/m³ for in relation to the previous value and 2.7 µg/m³ in relation to the start value and thus related to the start value outside of the permissible limit of B₀ = 2 µg/m³. This deviation only occurred one time during the entire field test campaign, a cause could not be determined. There was no externally triggered adjustment of the measuring device.

A regular external check of the sensitivity over the field test period could not be carried out, as suitable test equipment was not available before December 2013. As the devices have shown no drift effects during the permanent comparison with the standard reference method, this circumstance should not be relevant for the assessment of the measuring system, especially as it is intended to completely abstain from this test point in future for type approval testing according to EN TS 16450 [9].

Performance criterion met? no

6.6 Detailed presentation of test results

Table 23 and Table 24 provide the obtained measured values for zero point as well as the calculated deviations in relation to the previous and the starting value in µg/m³.

Figure 32 to Figure 35 provide a graphic representation of zero point drift over the course of testing.

Table 23: Zero point drift SN3 & SN4, PM₁₀, with zero filter

Date	SN3			Date	SN4		
	Measured Value	Deviation from previous value	Deviation from start value		Measured Value	Deviation from previous value	Deviation from start value
	µg/m³	µg/m³	µg/m³		µg/m³	µg/m³	µg/m³
11/19/2012	0.0	-	-	11/19/2012	0.0	-	-
11/20/2012	0.0	0.0	0.0	11/20/2012	0.0	0.0	0.0
11/21/2012	0.8	0.8	0.8	11/21/2012	0.8	0.8	0.8
1/11/2013	0.7	0.0	0.7	1/11/2013	0.1	-0.7	0.1
1/12/2013	0.4	-0.4	0.4	1/12/2013	0.0	0.0	0.0
1/13/2013	1.4	1.1	1.4	1/13/2013	1.0	1.0	1.0
2/5/2013	0.1	-1.3	0.1	2/5/2013	0.1	-0.9	0.1
2/6/2013	0.0	-0.1	0.0	2/6/2013	0.2	0.1	0.2
2/27/2013	1.0	0.9	1.0	2/27/2013	1.8	1.5	1.8
2/28/2013	1.4	0.4	1.4	2/28/2013	2.4	0.6	2.4
3/30/2013	1.2	-0.2	1.2	3/30/2013	2.0	-0.4	2.0
3/31/2013	1.0	-0.1	1.0	3/31/2013	2.7	0.8	2.7
4/1/2013	1.1	0.0	1.1	4/1/2013	2.2	-0.5	2.2
4/26/2013	1.1	0.1	1.1	4/26/2013	1.2	-1.0	1.2
4/27/2013	1.8	0.6	1.8	4/27/2013	1.6	0.4	1.6
4/28/2013	1.9	0.1	1.9	4/28/2013	1.8	0.2	1.8
5/15/2013	1.4	-0.5	1.4	5/15/2013	1.7	-0.1	1.7
5/16/2013	1.2	-0.2	1.2	5/16/2013	1.7	0.0	1.7
6/29/2013	1.6	0.4	1.6	6/29/2013	2.4	0.7	2.4
6/30/2013	1.5	-0.1	1.5	6/30/2013	2.2	-0.2	2.2
9/21/2013	1.5	0.0	1.5	9/21/2013	1.7	-0.5	1.7
2/7/2014*	1.8	0.3	1.8	2/7/2014	1.3	-0.4	1.3
2/8/2014*	2.4	0.6	2.4	2/8/2014	1.1	-0.2	1.1
2/9/2014*	1.9	-0.5	1.9	2/9/2014	1.2	0.1	1.2

* Cologne, Winter 2014, validation campaign

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Table 24: Zero point drift SN3 & SN4, PM_{2.5}, with zero filter

Date	SN3			Date	SN4		
	Measured Value	Deviation from previous value	Deviation from start value		Measured Value	Deviation from previous value	Deviation from start value
	µg/m³	µg/m³	µg/m³		µg/m³	µg/m³	µg/m³
11/19/2012	0.0	-	-	11/19/2012	0.0	-	-
11/20/2012	0.0	0.0	0.0	11/20/2012	0.0	0.0	0.0
11/21/2012	0.6	0.6	0.6	11/21/2012	0.6	0.6	0.6
1/11/2013	0.7	0.1	0.7	1/11/2013	0.1	-0.6	0.1
1/12/2013	0.3	-0.4	0.3	1/12/2013	0.0	0.0	0.0
1/13/2013	1.4	1.1	1.4	1/13/2013	1.0	0.9	1.0
2/5/2013	0.1	-1.4	0.1	2/5/2013	0.1	-0.8	0.1
2/6/2013	0.0	0.0	0.0	2/6/2013	0.2	0.1	0.2
2/27/2013	1.1	1.0	1.1	2/27/2013	1.7	1.5	1.7
2/28/2013	1.3	0.3	1.3	2/28/2013	2.4	0.6	2.4
3/30/2013	1.2	-0.1	1.2	3/30/2013	2.3	-0.1	2.3
3/31/2013	1.0	-0.2	1.0	3/31/2013	1.7	-0.6	1.7
4/1/2013	0.9	-0.1	0.9	4/1/2013	1.8	0.1	1.8
4/26/2013	1.1	0.2	1.1	4/26/2013	1.2	-0.5	1.2
4/27/2013	1.5	0.4	1.5	4/27/2013	1.6	0.4	1.6
4/28/2013	1.7	0.2	1.7	4/28/2013	1.7	0.1	1.7
5/15/2013	1.3	-0.3	1.3	5/15/2013	1.7	0.0	1.7
5/16/2013	1.1	-0.2	1.1	5/16/2013	1.6	-0.1	1.6
6/29/2013	1.5	0.4	1.5	6/29/2013	2.3	0.7	2.3
6/30/2013	1.5	-0.1	1.5	6/30/2013	2.2	-0.1	2.2
9/21/2013	1.5	0.0	1.5	9/21/2013	2.0	-0.2	2.0
2/7/2014*	2.0	0.5	2.0	2/7/2014	1.5	-0.5	1.5
2/8/2014*	2.4	0.4	2.4	2/8/2014	1.4	-0.1	1.4
2/9/2014*	2.1	-0.3	2.1	2/9/2014	1.4	0.0	1.4

* Cologne, winter 2014, validation campaign

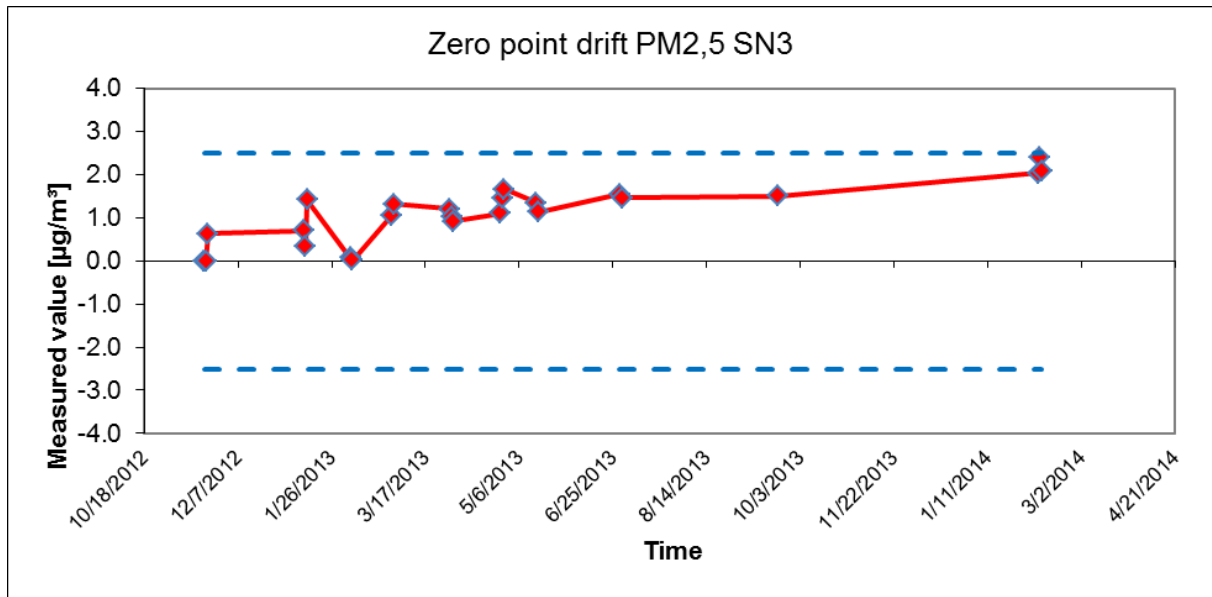


Figure 32: Zero point drift SN3, measured component PM_{2.5}

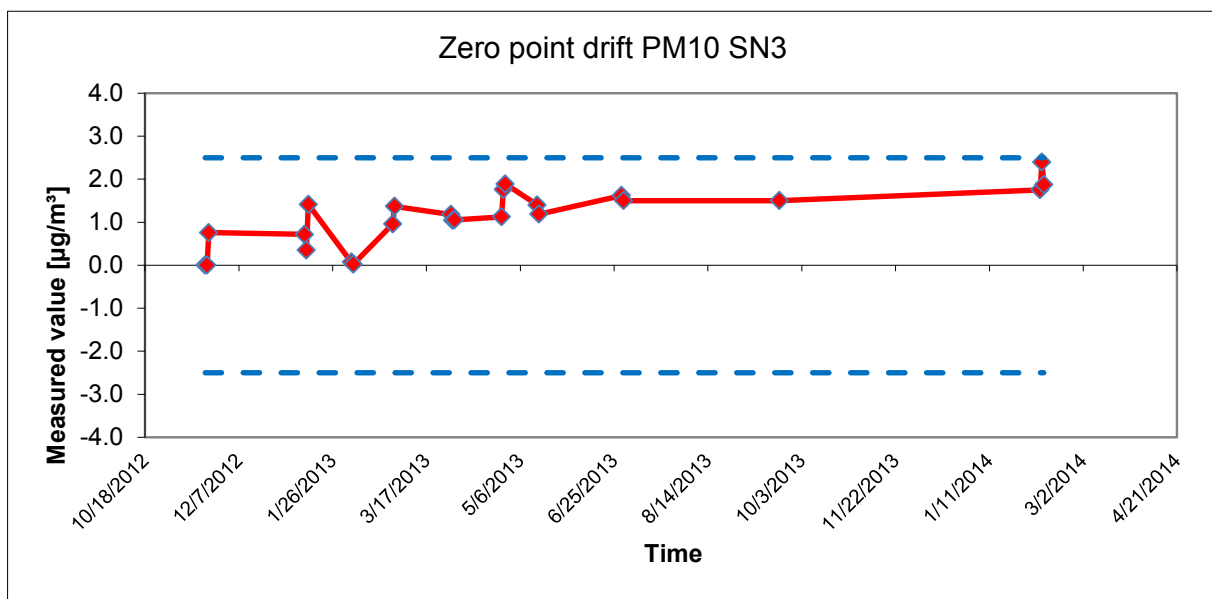


Figure 33: Zero point drift SN3, measured component PM₁₀

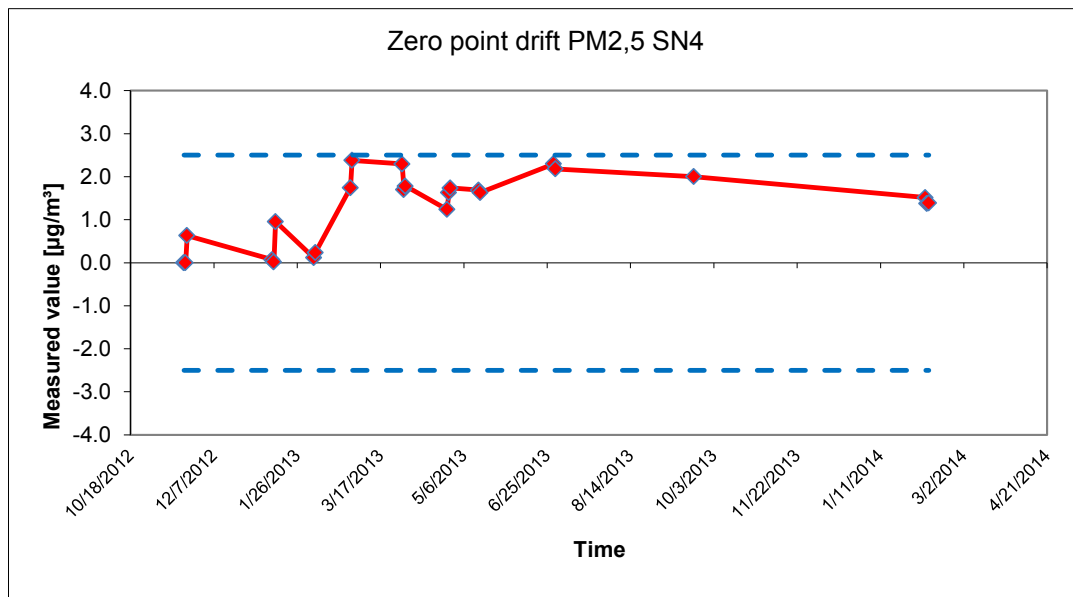


Figure 34: Zero point drift SN4, measured component PM_{2.5}

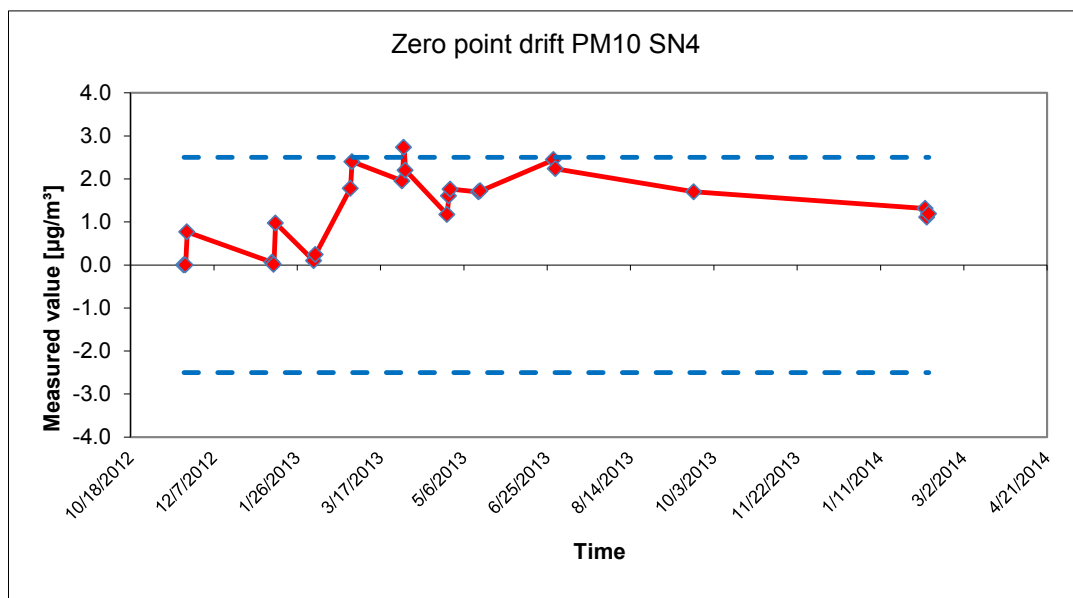


Figure 35: Zero point drift SN4, measured component PM₁₀

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6.1 5.3.13 Short-term drift

The short-term drift at zero point and reference point shall not exceed the requirements of Table 2 (VDI Standard 4202, Sheet 1; September 2010) within 12 h (for benzene 24 h) in the laboratory test and within 24 h in the field test. A value c_t at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.14 Response time

The response time (rise) of the measuring system shall not exceed 180 s.

The response time (fall) of the measuring system shall not exceed 180 s.

The difference between the response time (rise) and the response time (fall) of the measuring system shall not exceed 10 % of response time (rise) or 10 s, whatever value is larger.

Note:

This test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

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6.1 5.3.15 Difference between sample and calibration port

The difference between the measured values obtained by feeding gas at the sample and calibration port shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010). A value c_t at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.

Note:

This test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.16 Converter efficiency

In case of measuring systems with a converter, the converter efficiency shall be at least 98 %.

Note:

This test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

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6.1 5.3.17 Increase of NO₂ concentration due to residence in the AMS

In case of NO_x measuring systems the increase of NO₂ due to residence in the measuring system shall not exceed the requirements of Table 2 of VDI Standard 4202, Sheet 1 (September 2010).

The requirements of Table 2 of VDI Standard 4202, Sheet 1 apply to certification ranges according to Table 1 of VDI Standard 4202, Sheet 1 (September 2010). For deviating certification ranges the requirements shall be proportionally converted.

Note:

This test item is irrelevant to particulate measuring systems.

6.2 Equipment

Not applicable.

6.3 Method

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Performance criterion met? -

6.6 Detailed presentation of test results

Not applicable.

6.1 5.3.18 Overall uncertainty

The expanded uncertainty of the measuring system shall be determined. The value determined shall not exceed the corresponding data quality objectives in the applicable EU Directives on air quality listed in Annex A, Table A 1 of VDI Standard 4202, Sheet 1 (September 2010).

Note:

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems. Please refer to module 5.4.10.

6.2 Equipment

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems. Please refer to module 5.4.10.

6.3 Method

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems. Please refer to module 5.4.10.

6.4 Evaluation

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems. Please refer to module 5.4.10.

6.5 Assessment

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems. Please refer to module 5.4.10.

Performance criterion met? -

6.6 Detailed presentation of test results

By resolution of the relevant body in Germany (see module 5.3.1), this test item is irrelevant to particulate measuring systems. Please refer to module 5.4.10.

6.1 5.4.1 General

The testing of particulate measuring systems shall be carried out according to the minimum requirements set out in Table 5 of VDI Standard 4202, Sheet 1 (September 2010). Particle mass concentrations shall be related to a defined volume. The relation to volume with respect to pressure and temperature shall be comprehensively described.

6.2 Equipment

No equipment is necessary to test this performance criterion.

6.3 Method

The test was carried out according to the minimum requirements set out in Table 5 of VDI Standard 4202, Sheet 1 (September 2010).

To determine whether the measured particle mass concentrations are related to a defined volume was the objective of the test.

6.4 Evaluation

The test was carried out according to the minimum requirements set out in Table 5 of VDI Standard 4202, Sheet 1 (September 2010).

The APM-2 measuring system is an optical measuring system which first determines the scattered light signal, induced by particles in a defined measured volume, and then converts the available information into concentration values by means of an algorithm. The measured signal for the particles is therefore related to a defined volume (measured volume).

6.5 Assessment

The test was carried out according to the minimum requirements set out in Table 5 of VDI Standard 4202, Sheet 1 (September 2010).

The APM-2 measuring system is an optical measuring system which first determines the scattered light signal, induced by particles in a defined measured volume, and then converts the available information into concentration values by means of an algorithm. The measured signal for the particles is therefore related to a defined volume (measured volume).

Performance criterion met? yes

6.6 Detailed presentation of test results

No equipment is necessary to test this performance criterion.

6.1 5.4.2 Equivalency of the sampling system

The equivalency between the PM₁₀ sampling system and the reference method according to Standard EN 12341 [T5] shall be demonstrated.

Not applicable to PM_{2.5} sampling systems. Please refer to module 5.4.10 in this report.

6.2 Equipment

The performance criterion was tested with the additional equipment described in chapter 5 of this report.

6.3 Method

As described in chapter 4 of this report, the test was carried out at various sites during the field test. Different seasons as well as different PM₁₀ concentrations were taken into account.

At least 15 valid data pairs were obtained at each test site.

6.4 Evaluation

Requirement according to Standard EN 12341:

The calculated functional correlation $y = f(x)$ between the candidate (y) and the concentration values measured by the reference device (x) shall be limited by a two sided acceptance envelope. This acceptance envelope is defined by:

$$y = (x \pm 10) \mu\text{g}/\text{m}^3 \text{ for concentration mean values } \leq 100 \mu\text{g}/\text{m}^3 \text{ and}$$

$$y = 0.9x \mu\text{g}/\text{m}^3 \text{ or } 1.1x \mu\text{g}/\text{m}^3 \text{ for concentration mean values } > 100 \mu\text{g}/\text{m}^3$$

Furthermore, the variation coefficient R^2 of the calculated reference-equivalence function shall not fall below the value of 0.95.

The test is directed towards the functional correlation between the concentration values obtained from paired determinations between the candidate and the reference device. Ideally, both systems measure the same mass fraction of suspended particulate matter so that $y = x$. The evaluation procedure is as follows:

A linear regression analysis was carried out for the measured values obtained at all four test sites individually and as a whole.

A reference equivalence function corresponding to the equation below is determined for each measured value y_i of the respective candidate and of the reference device x (both in $\mu\text{g}/\text{m}^3$).

$$y_i = m \cdot x + b$$

with i = candidate APM-2

6.5 Assessment

For SN3, the reference equivalence functions for the (uncorrected) datasets lie outside the limits of the respective acceptance envelope for all test sites with exception of Cologne, winter, for SN4 only the reference equivalence function for the field campaign Rodenkirchen is outside of the respective acceptance envelope. Moreover, the variation coefficient R^2 of the calculated reference equivalence function in the concentration range concerned is < 0.95 for all comparison campaigns with exception of Cologne, winter. The demonstration of equivalence according to EN 12341:1998 is thus not possible. Nevertheless, the equivalence test according to the EC-guide, which is relevant for the end user, is passed after application of the necessary correction factors for all test sites without restrictions (refer to 6.1 5.4.11

Application of correction factors and terms).

Performance criterion met? no

6.6 Detailed presentation of test results

Table 25 and Table 26 present a summary of the results of the regression analyses. Figure 36 to Figure 45 provide graphical representations which illustrate these findings. In addition to the regression lines of both candidates, the diagrams show the curve $y = x$, which is considered ideal and the two-sided acceptance envelope. All individual values for the candidates as well as for the reference devices are listed separately for each test site in annex 5 of the appendix.

Table 25: *Results of the linear regression analysis of measurements with both candidates SN3 and SN4 at all four sites, raw data*

SN3	Number of paired values N	Slope m	Intercept b	R²
Cologne, winter	52	0.922	-1.779	0.968
Bonn, winter	51	0.876	-2.419	0.861
Cologne, summer	47	0.830	-1.253	0.911
Rodenkirchen, summer	45	0.880	-3.745	0.804
SN4	Number of paired values N	Slope m	Intercept b	R²
Cologne, winter	52	0.976	-1.068	0.974
Bonn, winter	51	0.964	-2.705	0.863
Cologne, summer	45	0.927	-1.669	0.917
Rodenkirchen, summer	45	0.893	-4.320	0.822

Table 26: *Results of the linear regression analysis of measurements with both candidates SN3 and SN4 (total), raw data*

Candidate	Number of paired values N	Slope m	Intercept b	R²
SN3	195	0.894	-2.590	0.914
SN4	193	0.972	-3.010	0.907

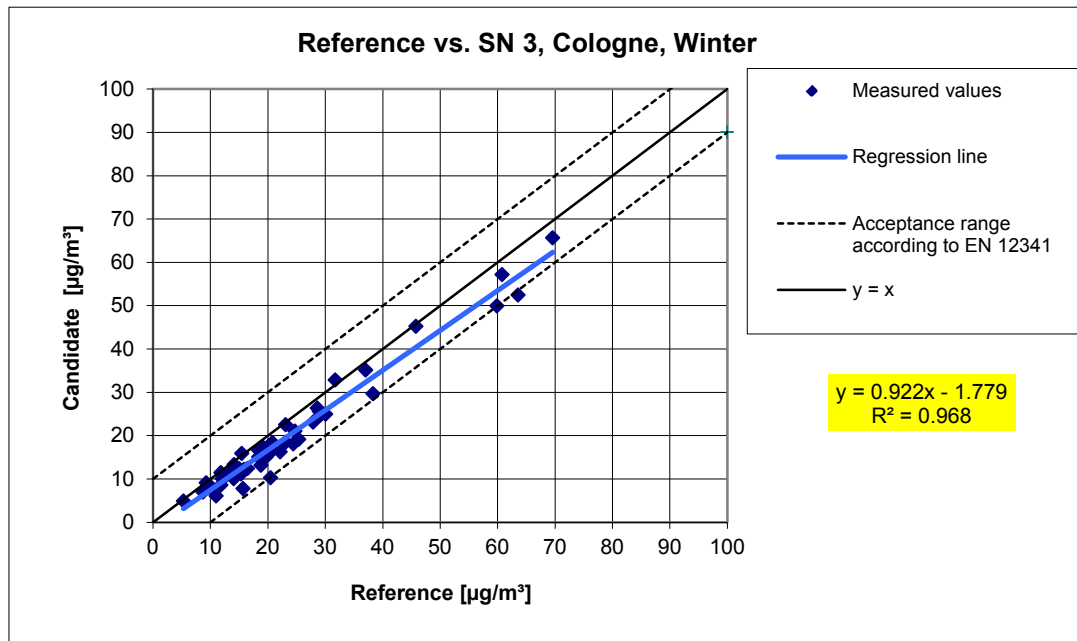


Figure 36: Reference equivalence function SN3, test site Cologne, winter

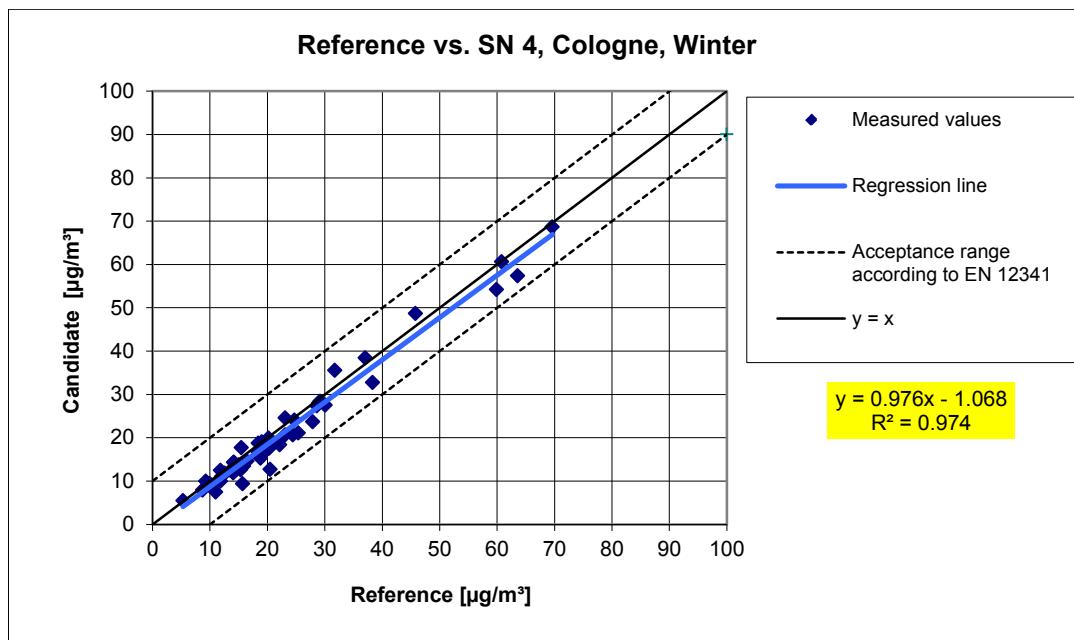


Figure 37: Reference equivalence function SN4, test site Cologne, winter

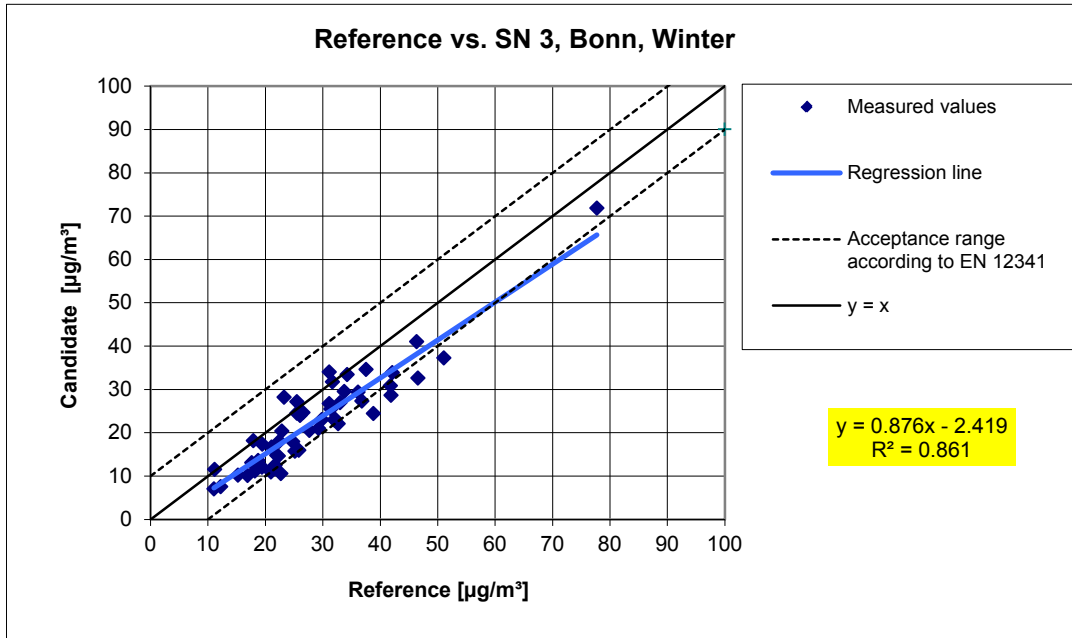


Figure 38: Reference equivalence function SN3, test site Bonn, winter

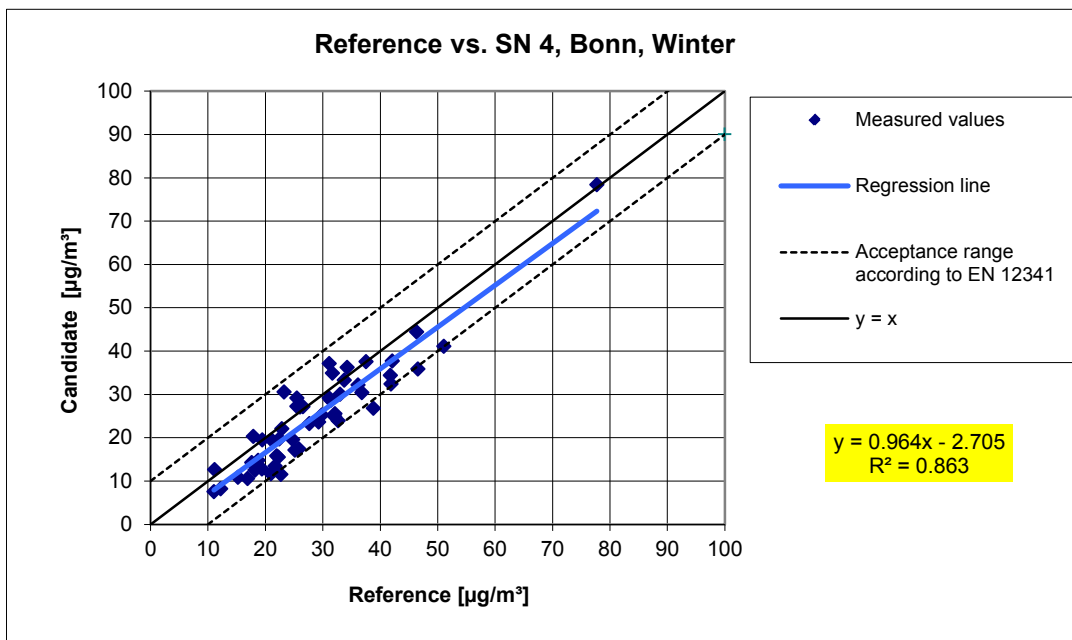


Figure 39: Reference equivalence function SN4, test site Bonn, winter

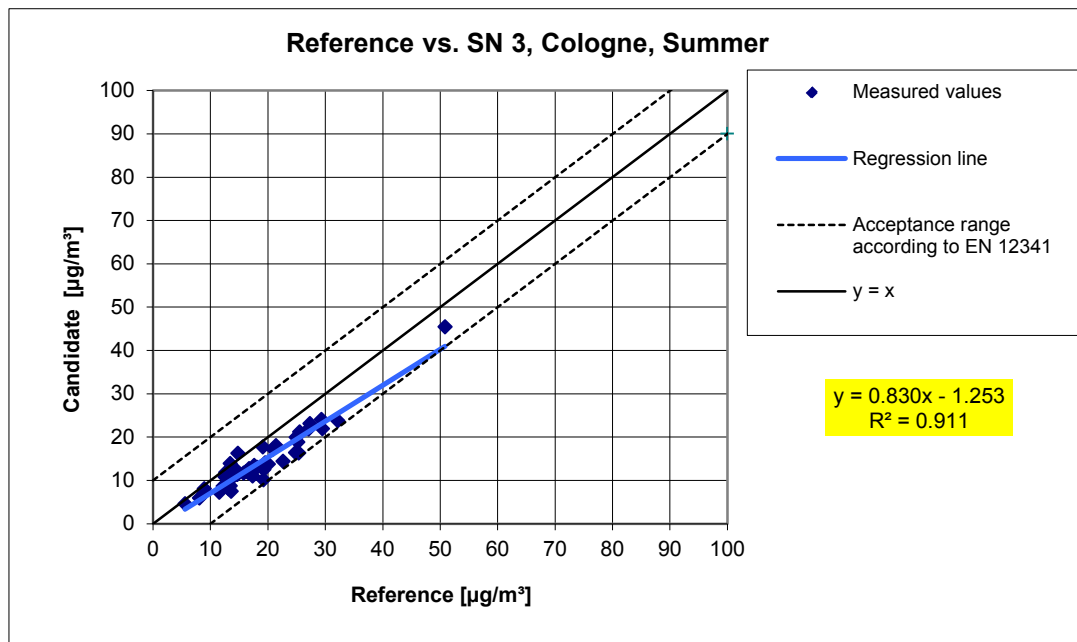


Figure 40: Reference equivalence function SN3, test site Cologne, summer

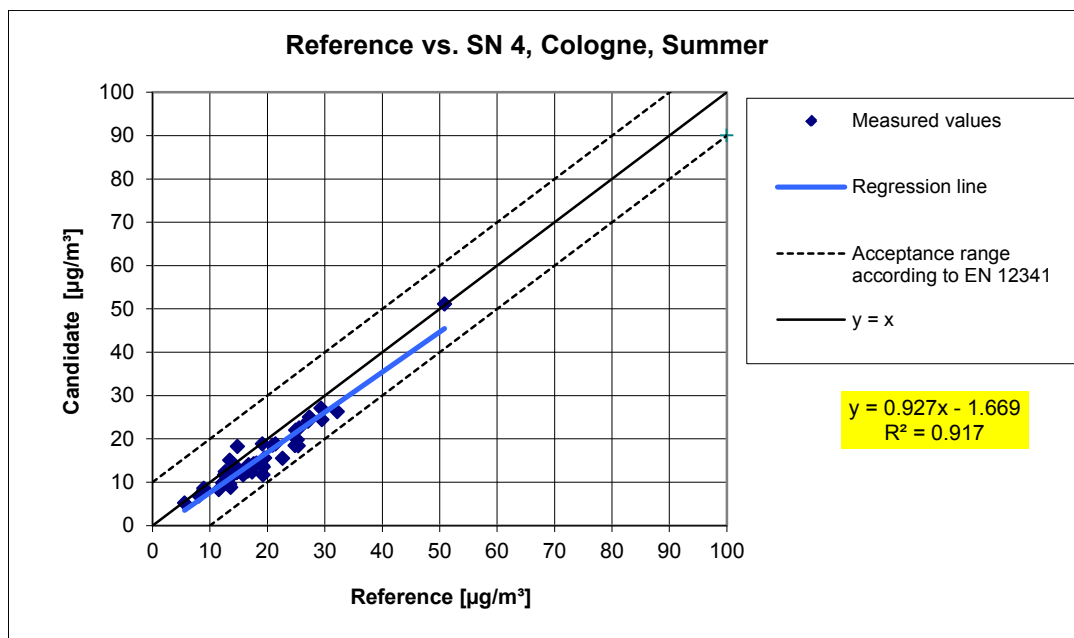


Figure 41: Reference equivalence function SN4, test site Cologne, summer

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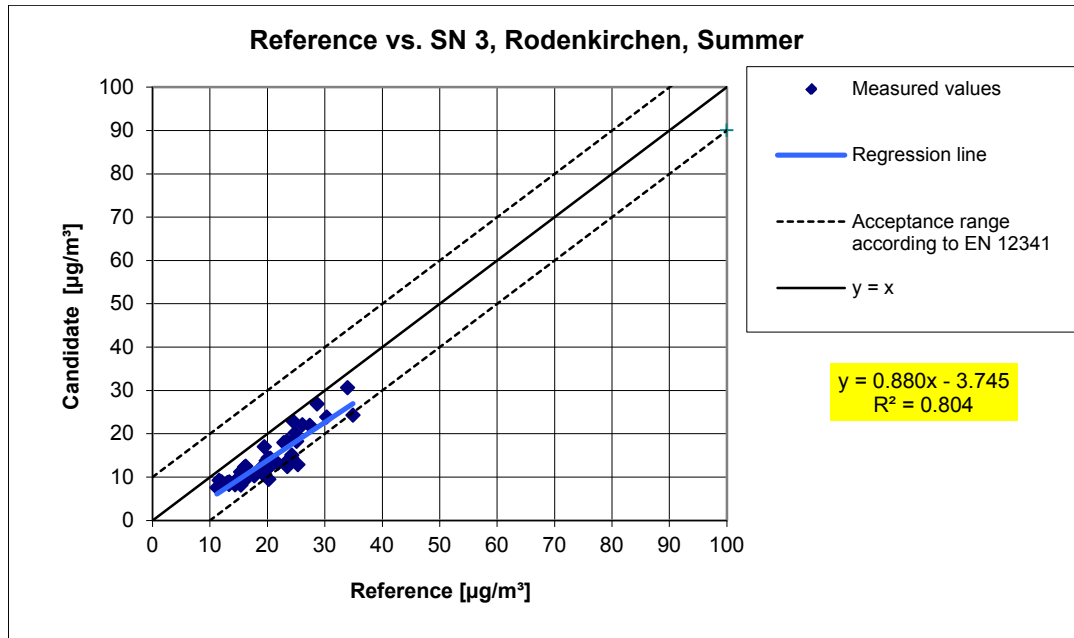


Figure 42: Reference equivalence function SN3, test site Rodenkirchen, summer

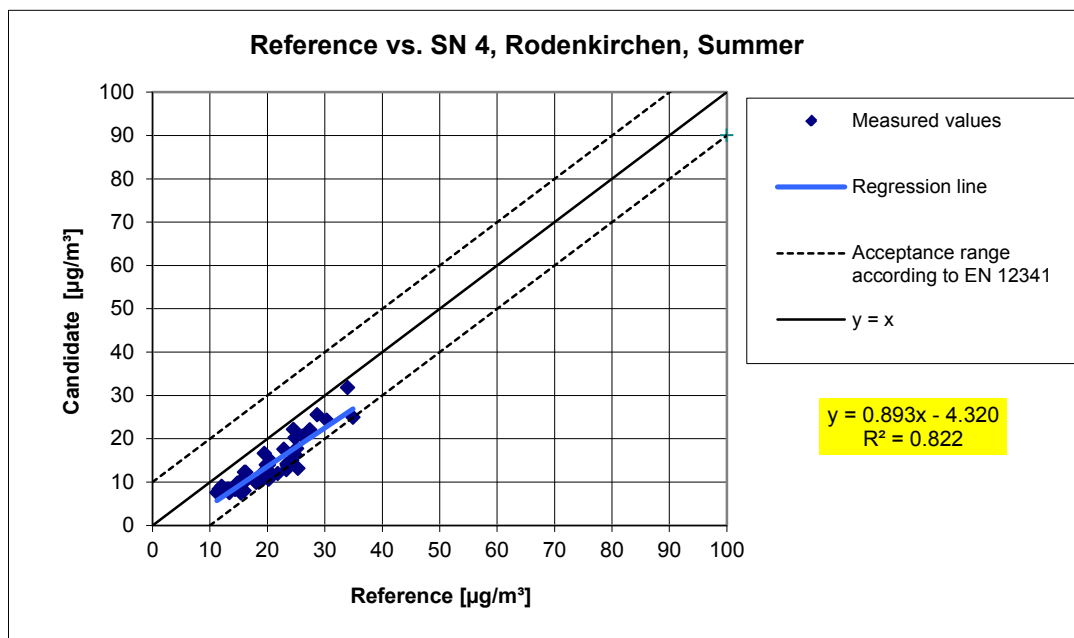


Figure 43: Reference equivalence function SN4, test site Rodenkirchen, summer

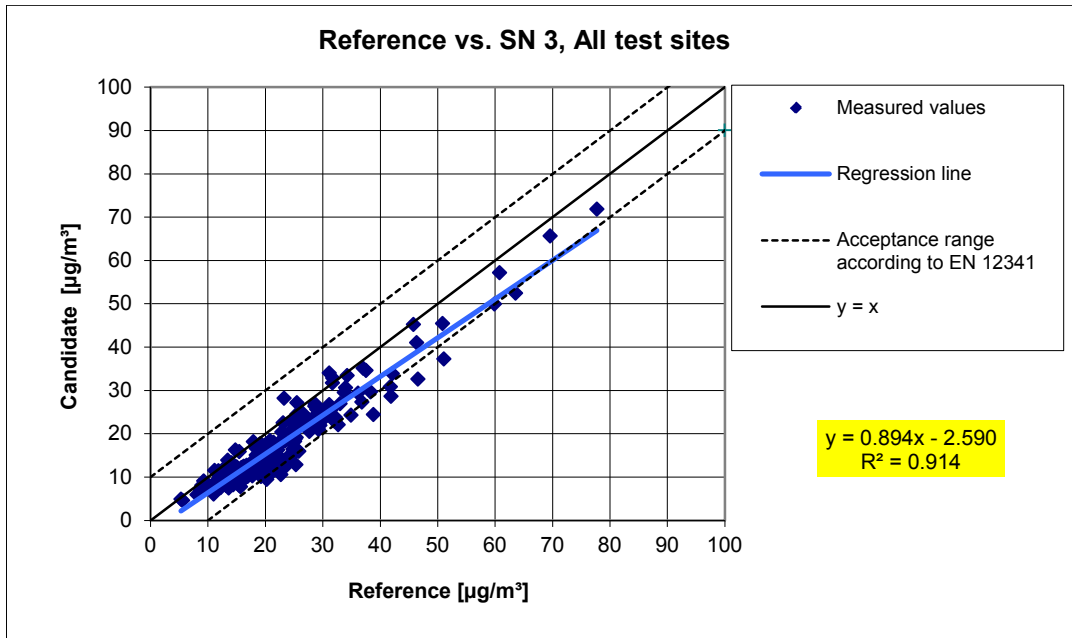


Figure 44: Reference equivalence function SN3, all sites

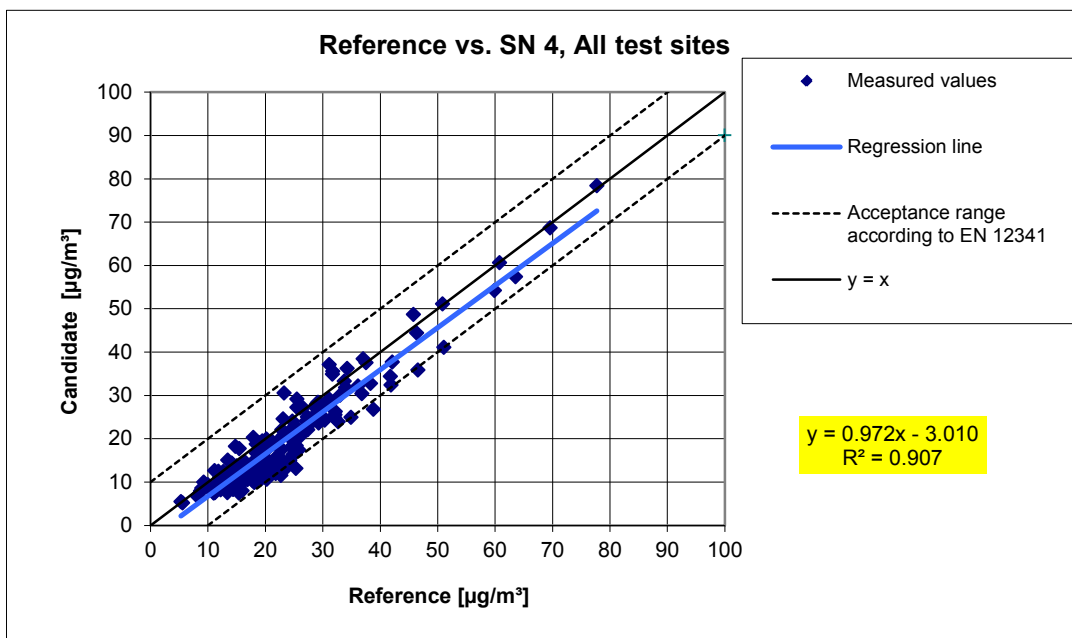


Figure 45: Reference equivalence function SN4, all sites

6.1 5.4.3 Reproducibility of the sampling systems

The PM₁₀ sampling systems of two identical systems under test shall be reproducible among themselves according to Standard EN 12341 [T5]. This shall be demonstrated in the field test.

Not applicable to PM_{2.5} sampling systems. Please refer to module 5.4.10 in this report.

6.2 Equipment

No equipment is necessary to test this performance criterion.

6.3 Method

The test was carried out at various test sites according to item 4 in this report. Different seasons as well as different PM₁₀ concentrations were taken into account.

At least 15 valid data pairs were obtained per site.

6.4 Evaluation

The two-sided confidence interval CI_{95} calculated from the concentration mean values measured by the candidates shall not exceed 5 µg/m³ if the average concentration is ≤ 100 µg/m³. If the average concentration is > 100 µg/m³, the confidence interval shall not exceed 0.05.

The demonstration of the reproducibility of the candidates focuses on the differences D_i between the concentration values Y_i measured by the candidates. Ideally, both candidates are identical and therefore measure the same mass fraction of suspended particulate matter so that $D_i = 0$. The evaluation procedure is as follows:

First, the concentration mean values Y_i are calculated from the concentration values measured simultaneously by both candidates. Then the concentration mean values Y_i are split into two separate datasets:

- a) Dataset with $Y_i \leq 100 \text{ µg/m}^3$ with number of data pairs n_{\leq} and
- b) Dataset with $Y_i > 100 \text{ µg/m}^3$ with number of data pairs $n_{>}$

With respect to a):

The data pairs of the dataset with $Y_i \leq 100 \text{ µg/m}^3$ are used to calculate the absolute standard deviation s_a :

$$s_a = \sqrt{(\sum D_i^2 / 2n_{\leq})}$$

The Student's factor $t_{f_{\leq}, 0.975}$, which is defined as the 0.975 quantile of the two-sided 95 % confidence interval of the Student's t-distribution with $f_{\leq} = n_{\leq} - 2$ degrees of freedom, is applied.

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The two-sided 95% confidence interval Cl_{95} for concentration mean values $\leq 100 \mu\text{g}/\text{m}^3$ is calculated as follows:

$$Cl_{95} = s_a \cdot t_{f_{\leq}; 0,975}$$

With respect to b):

The relative standard deviation s_r is calculated from the data pairs of the dataset with $Y_i > 100 \mu\text{g}/\text{m}^3$:

$$s_r = \sqrt{(\sum (D_i / Y_i)^2 / 2n_{>})}$$

Again, the Student's factor $t_{f_{>}; 0,975}$ defined as 0.975 quantile of the two-sided 95 % confidence interval of the Student's t-distribution with $f_{>} = n_{>} - 2$ degrees of freedom is applied.

The two-sided 95 % confidence interval Cl_{95} for concentration mean values $> 100 \mu\text{g}/\text{m}^3$ is calculated as follows:

$$Cl_{95} = s_r \cdot t_{f_{>}; 0,975}$$

During the field tests, no concentration values $> 100 \mu\text{g}/\text{m}^3$ were observed. For that reason, a statistical evaluation is not possible. Hence, consideration according to b) is not required.

6.5 Assessment

The following is applicable to all field test sites:

The two-sided confidence interval Cl_{95} of max. $3.58 \mu\text{g}/\text{m}^3$ is below the permissible limit of $5 \mu\text{g}/\text{m}^3$.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 27 lists the calculated values of the standard deviation s_a and the two-sided confidence interval Cl_{95} . Figure 46 to Figure 50 provide the graphical representation. Aside from the regression line of both candidates (calculated by means of linear regression analysis), the diagram shows the $y = x$ curve, which is considered ideal, and the two-sided acceptance envelope. All single values for the candidates are provided in annex 5.

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Table 27: Two-sided 95% confidence interval CI_{95} for the tested devices SN3 and SN4

Candidates	Test site	Number of values	Standard deviation s_a	Student's-factor t_f	Confidence interval CI_{95}
SN			$\mu\text{g}/\text{m}^3$		$\mu\text{g}/\text{m}^3$
SN3/SN4	Cologne, winter	69	1.44	1.996	2.87
SN3/SN4	Bonn, winter	61	1.79	2.001	3.58
SN3/SN4	Cologne, summer	54	1.16	2.007	2.32
SN3/SN4	Rodenkirchen, summer	53	0.69	2.008	1.38
SN3/SN4	Total	237	1.35	1.970	2.67

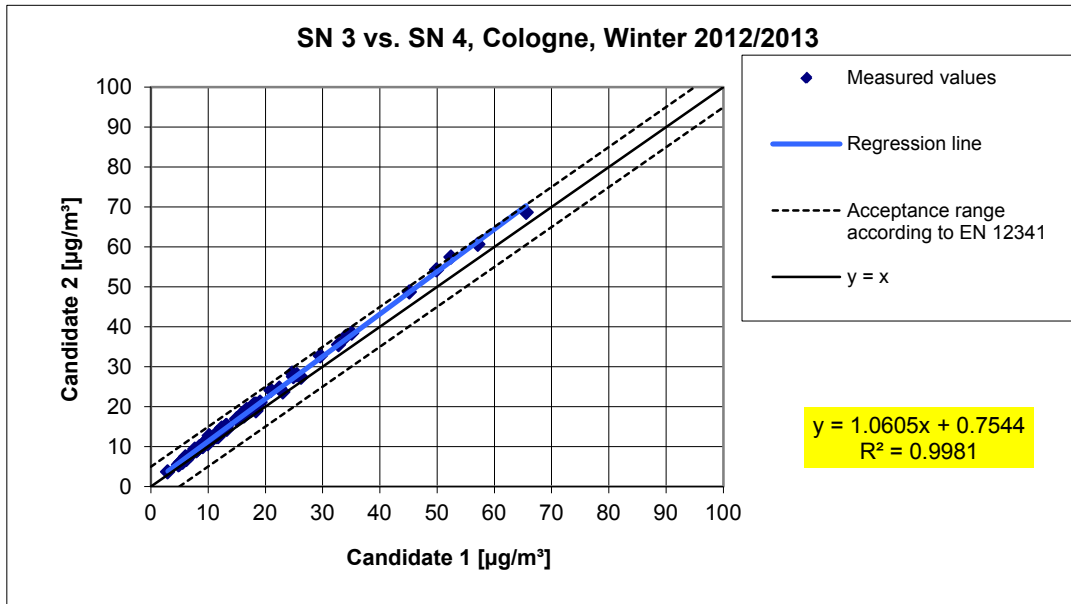


Figure 46: Results of parallel measurements with the tested devices SN3 / SN4, test site Cologne, winter

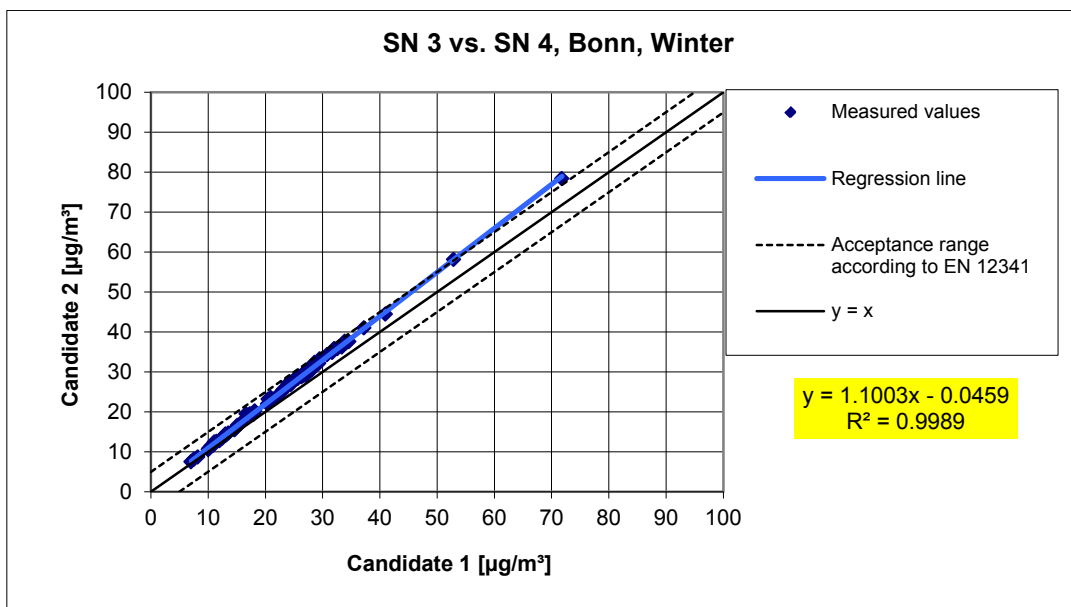


Figure 47: Results of parallel measurements with the tested devices SN3 / SN4, test site Bonn, winter

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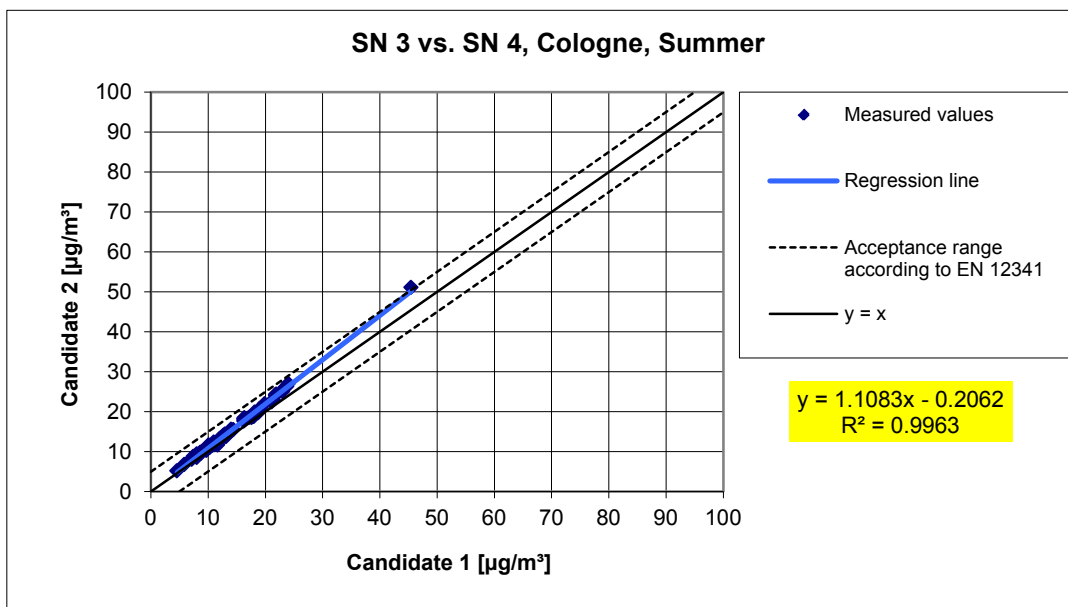


Figure 48: Results of parallel measurements with the tested devices SN3 / SN4, test site Cologne, summer

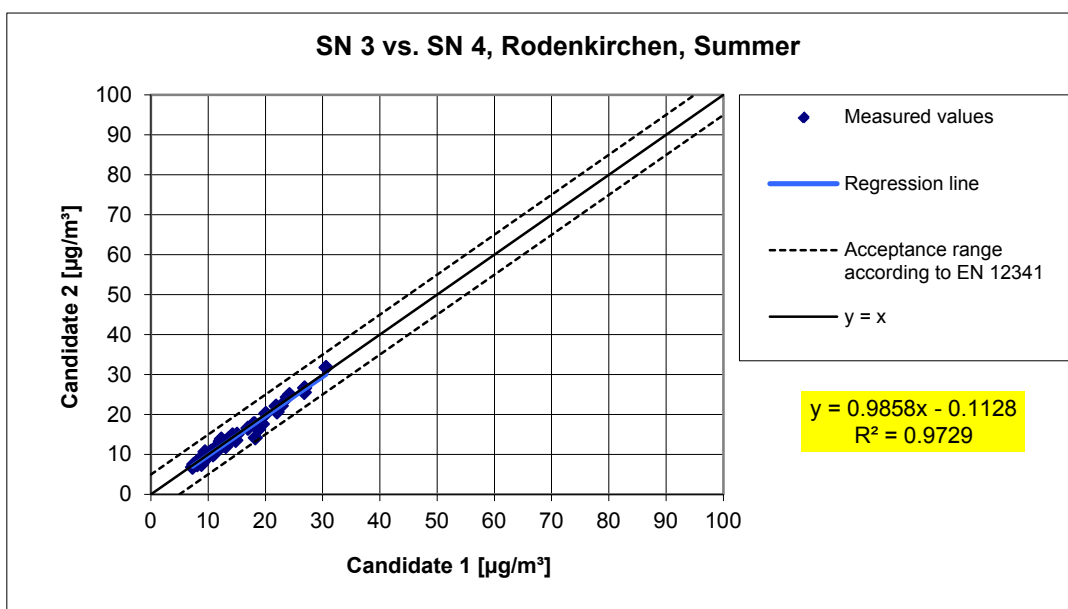


Figure 49: Results of parallel measurements with the tested devices SN3 / SN4, test site Rodenkirchen, summer

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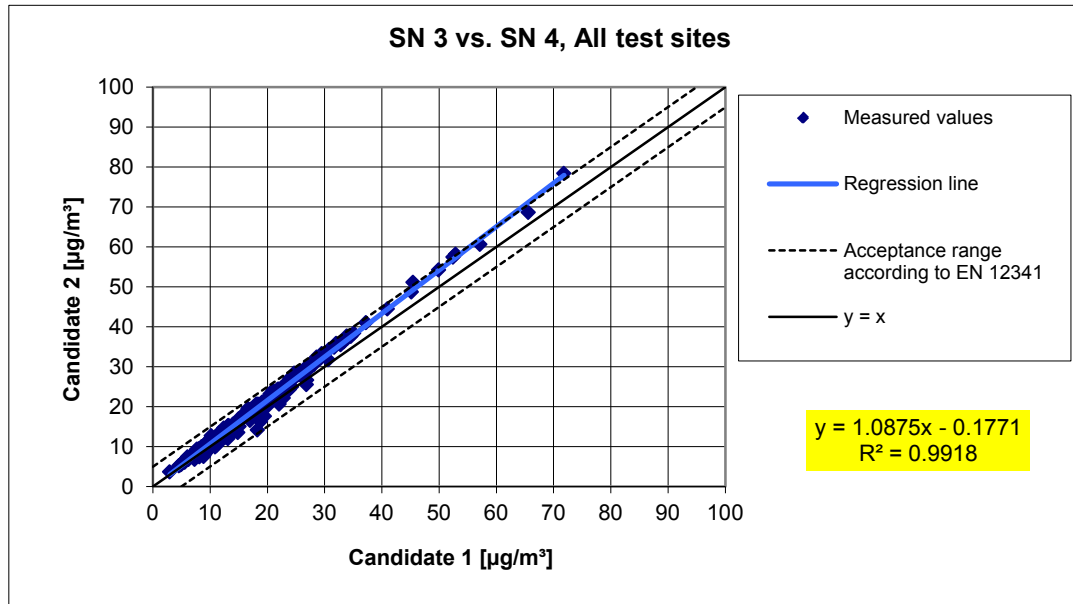


Figure 50: Results of parallel measurements with the tested devices SN3 / SN4, all test sites

6.1 5.4.4 Calibration

The systems under test shall be calibrated in the field test by comparison measurements with the reference method according to Standard EN 12341 respectively EN 14907. Here, the relationship between the output signal and the gravimetrically determined reference concentration shall be determined as a steady function.

6.2 Equipment

Refer to module 5.4.2. or module 5.4.10

6.3 Method

For PM₁₀:

The reproducibility of the measuring systems was proven during testing (refer to module 5.4.2).

In order to determine the calibration function and the analytical function, the complete dataset was used (195 valid data pairs (SN3) and 193 valid data pairs (SN4)).

The quantities of the calibration function

$$y = m \cdot x + b$$

were determined by means of linear regression. The analytical function is the inverse of the calibration function. It is:

$$x = 1/m \cdot y - b/m$$

The slope m of the regression line describes the sensitivity of the measuring system; the y -intercept b describes the zero point.

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For PM_{2.5}:

The reproducibility of the measuring systems as per module 5.4.10 was proven during testing.

In order to determine the calibration function and the analytical function, the complete dataset was used (194 valid data pairs (SN3) and 192 valid data pairs (SN4)).

The quantities of the calibration function

$$y = m \cdot x + b$$

were determined by means of orthogonal regression. The analytical function is the inverse of the calibration function. It is:

$$x = 1/m \cdot y - b/m$$

The slope m of the regression line describes the sensitivity of the measuring system, the y-intercept b describes the zero point.

6.4 Evaluation

The resulting quantities for PM₁₀ are given in Table 28.

Table 28: Results of the calibration function and analytical function, measured component PM₁₀

Device no.	Calibration function		Analytical function	
	$Y = m \cdot x + b$		$x = 1/m \cdot y - b/m$	
	m	b	1/m	b/m
	µg/m³ / µg/m³	µg/m³	µg/m³ / µg/m³	µg/m³
System 1 (SN3)	0.894	-2.590	1.119	-2.897
System 2 (SN4)	0.972	-3.010	1.029	-3.097

The resulting quantities for PM_{2.5} are given in Table 29.

Table 29: Results of the calibration function and analytical function, measured component PM_{2.5}

Device no.	Calibration function		Analytical function	
	$Y = m \cdot x + b$		$x = 1/m \cdot y - b/m$	
	m	b	1/m	b/m
	µg/m³ / µg/m³	µg/m³	µg/m³ / µg/m³	µg/m³
System 1 (SN3)	0.896	0.382	1.116	0.426
System 2 (SN4)	0.943	0.267	1.060	0.283

6.5 Assessment

A statistical correlation between the reference measuring method and the output signal could be demonstrated.

Performance criterion met? yes

6.6 Detailed presentation of test results

Refer to modules 5.4.2. and 5.4.10.

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6.1 5.4.5 Cross sensitivity

The interference caused by moisture in the sample may not exceed 10 % of the limit value in the range of the limit value.

6.2 Equipment

Not required here.

6.3 Method

The interference caused by moisture in the sample was determined under field conditions.

Using the data from field test days with a relative humidity of > 70 % the difference between the obtained reference value (= nominal value) and the measured values of each candidate was calculated and the mean difference was applied as a conservative estimate for the interference caused by moisture in the sample.

In addition to that, reference/equivalence functions were determined for both devices using the data from field test days with a relative humidity of > 70 %.

6.4 Evaluation

Using the data from field test days with a relative humidity of > 70 %, the mean difference between the calculated reference value (= nominal value) and the measured value of the respective candidate was calculated and the relative deviation from the mean concentration was determined.

Annual limit value PM_{2.5} = 25 µg/m³

10 % of the annual limit value = 2.5 µg/m³

Annual limit value PM₁₀ = 40 µg/m³

10 % of the annual limit value = 4 µg/m

It was also examined whether the reproducibility of the measuring systems under test using the reference method according to Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods" [5] can be ensured even if the measured values were obtained on days with a relative humidity of > 70 %.

6.5 Assessment

No deviation of the measured signal from the nominal value $> -1.1 \mu\text{g}/\text{m}^3$ caused by interference due to moisture in the sample could be observed for PM_{2.5}. For PM₁₀, no deviation of the measured signal from the nominal value $> 0.9 \mu\text{g}/\text{m}^3$ caused by interference due to moisture in the sample could be observed. The comparability of the candidates with the reference method according to the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods" [5] is ensured even for days with a relative humidity of $> 70 \%$.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 30 and Table 31 provide summaries of the results.

Table 30: Deviation between reference measurement and candidate on days with a relative humidity of $> 70 \%$, measured component PM_{2.5}

Field test, days with rel. humidity $> 70 \%$				
		Reference	SN 3	SN 4
Mean value	$\mu\text{g}/\text{m}^3$	15.5	14.4	15.0
Dev. to mean value of reference in $\mu\text{g}/\text{m}^3$	$\mu\text{g}/\text{m}^3$	-	-1.1	-0.4
Dev. in % of mean value reference	%	-	-6.8	-2.9
Deviation in % of annual LV	%	-	-4.2	-1.8

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Table 31: Deviation between reference measurement and candidate on days with a relative humidity of > 70 %, measured component PM₁₀

Field test, days with rel. humidity >70 %				
		Reference	SN 3	SN 4
Mean value	µg/m ³	21.5	21.0	22.4
Dev. to mean value of reference in µg/m ³	µg/m ³	-	-0.4	0.9
Dev. in % of mean value reference	%	-	-2.1	4.4
Deviation in % of annual LV	%	-	-1.1	2.4

Single values are provided in annexes 5 and 6.

The measurement uncertainties W_{CM} on days with a relative humidity of > 70 % are presented in Table 32 and Table 33. Single values are provided in annexes 5 and 6.

Table 32: Comparison of the candidates SN3 / SN4 with the reference device, rel. humidity > 70 %, all test sites, measured component PM_{2.5}

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010				
Candidate	APM-2	SN	SN3 & SN4	
Status of measured values	Raw data	Limit value	30	µg/m ³
		Allowed uncertainty	25	%
All test sites, rH>70%				
Uncertainty between Reference	0.53	µg/m ³		
Uncertainty between Candidates	0.63	µg/m ³		
	SN3		SN4	
Number of data pairs	116		116	
Slope b	0.885		0.927	
Uncertainty of b	0.013		0.014	
Ordinate intercept a	0.729		0.671	
Uncertainty of a	0.263		0.280	
Expanded meas. uncertainty W_{CM}	21.29	%	15.71	%

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Table 33: *Comparison of the candidates SN3 / SN4 with the reference device, rel. humidity > 70 %, all test sites, measured component PM₁₀*

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010				
Candidate	APM-2	SN	SN3 & SN4	
Status of measured values	Offset corrected	Limit value	50	µg/m³
		Allowed uncertainty	25	%
All test sites, rH>70%				
Uncertainty between Reference	0.56	µg/m³		
Uncertainty between Candidates	1.29	µg/m³		
	SN3	SN4		
Number of data pairs	116	116		
Slope b	0.947	1.021		
Uncertainty of b	0.022	0.025		
Ordinate intercept a	0.635	0.471		
Uncertainty of a	0.557	0.611		
Expanded measured uncertainty W _{CM}	14.55	%	14.64	%

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6.1 5.4.6 Averaging effect

The measuring system shall allow the formation of 24 h mean values.

The time of the sum of all filter changes within 24 h shall not exceed 1 % of this averaging time.

6.2 Equipment

Additionally a timer was used.

6.3 Method

It was tested, whether the AMS allows the formation of daily mean values.

6.4 Evaluation

The APM-2 measuring system switches alternatingly every two minutes between the measuring channels for PM₁₀ and PM_{2.5}. Additionally once per hour the photometer unit is purged with zero air for two minutes.

Thus the available acquisition per PM-fraction is $((60\text{min}-2\text{min})/2) = 29 \text{ min}$ per hour and thus at 48.3 % of the total time.

The results from the field investigations according to chapter 6.1 5.4.10 Calculation of expanded uncertainty between systems under test and chapter 6.1 5.4.11 Application of correction factors and terms in the report at hand nevertheless show, that the comparability of the candidate systems with the reference method has been demonstrated in the tested candidate configuration and that the formation of valid daily mean values is possible – this is also valid for the strongly traffic-influenced test site at the crossroads in Bonn.

Thus, the formation of daily mean values can be guaranteed.

6.5 Assessment

The measuring system allows the formation of valid daily mean values.

Performance criterion met? yes

6.6 Detailed presentation of test results

Not required here.

6.1 5.4.7 Constancy of sample volumetric flow

The sample volumetric flow averaged over the sampling time shall be constant within $\pm 3\%$ of the rated value. All instantaneous values of the sample volumetric flow shall be within a range of $\pm 5\%$ of the rated value during sampling.

6.2 Equipment

As indicated in chapter 4, a flow meter was used in the testing of this performance criterion.

6.3 Method

The sample volumetric flow was calibrated before testing at the first field test site. Before testing at the other field test sites it was checked for correctness with a mass flow meter and readjusted if necessary.

The APM-2 measuring system operates with a flow rate of 3.3 l/min.

In order to determine the constancy of sample volumetric flow, the flow rate was recorded over 24 h (SN4) respectively 21 h (SN3) by means of a mass flow meter and evaluated according to the relevant upcoming test item 7.4.5 "Constancy of sample flow rate" of Technical Specification EN TS 16450 (May 2013) [9].

6.4 Evaluation

The obtained measured values for the flow rate were used to calculate mean value, standard deviation as well as maximum and minimum value.

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6.5 Assessment

The results of the flow rate checks carried out at each field test site are given in Table 34.

Table 34: Results of flow rate checks

Flow rate check before testing at Test site:	SN3		SN4	
	[l/min]	Deviation from nominal value [%]	[l/min]	Deviation from nominal value [%]
Cologne, winter	3.31	0.3	3.30	0
Bonn, winter	3.32	0.6	3.28	-0.6
Cologne, summer	3.33	0.9	3.29	-0.3
Rodenkirchen, summer	3.36	1.8	3.33	0.9

The graphical representations of flow rate constancy show that none of the values obtained during sampling deviates from the respective nominal value by more than ± 5 %. The 24 h mean values for the total flow rate of 3.3 l/min also deviate significantly less than the permissible ± 3 % from the nominal value.

All determined daily mean values deviate less than ± 3 % from the rated value and all instantaneous values deviate less than ± 5 %.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 35 shows the parameters determined for the flow. Figure 51 and Figure 52 present a graphic representation of the flow measurements of the two candidates SN3 and SN4.

Table 35: Parameters for total flow measurement (24 h mean), SN3 & SN4

Device	Mean [l/min]	Deviation from nominal [%]	Std. dev. [l/min]	Max [l/min]	Min [l/min]
SN3	3.29	-0.43	0.033	3.45	3.20
SN4	3.31	0.24	0.030	3.37	3.27

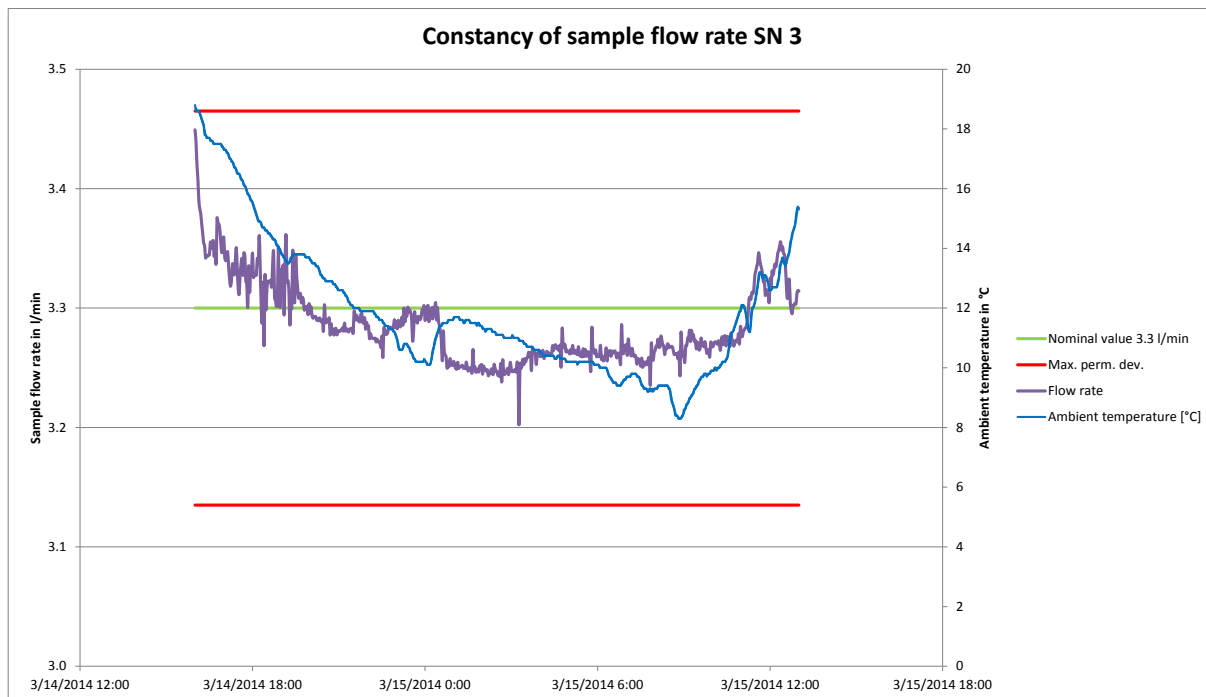


Figure 51: Flow rate of device SN3 (field conditions)

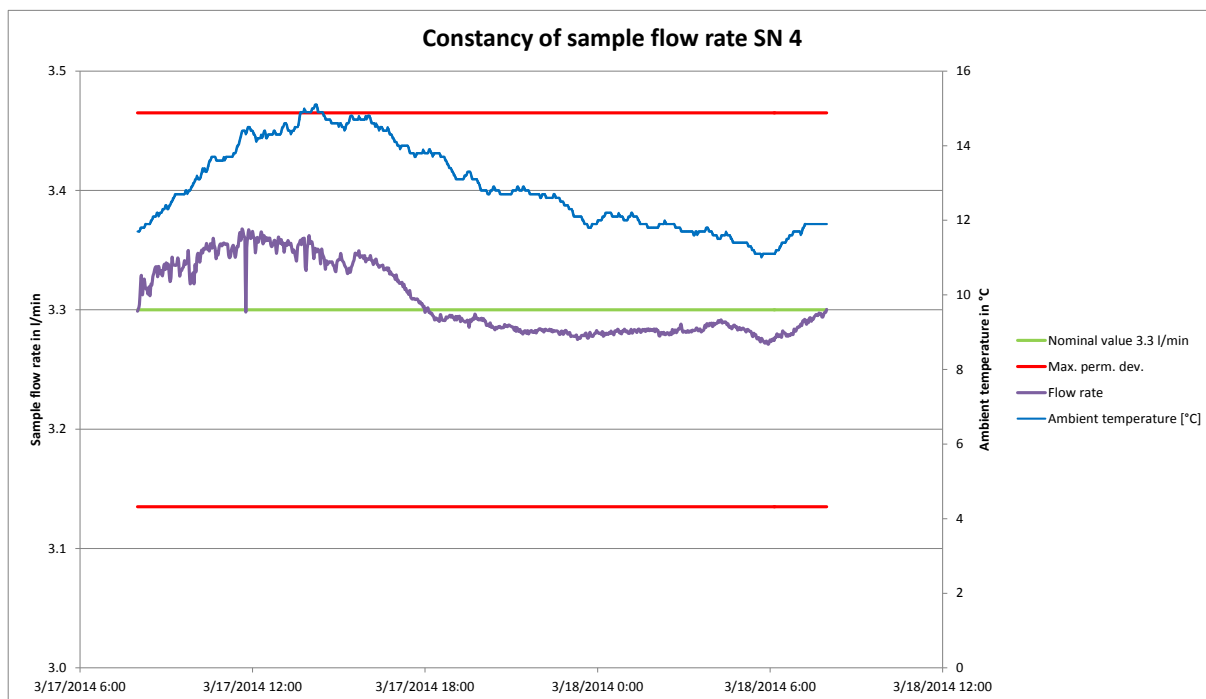


Figure 52: Flow rate of device SN4 (field conditions)

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6.1 5.4.8 Tightness of the measuring system

The complete measuring system shall be checked for tightness. Leakage shall not exceed 1 % of the sample volume sucked.

6.2 Equipment

Not required here.

6.3 Method

The flow meter of the APM-2 measuring system is located directly upstream the pump. To determine the leak rate of the AMS, a leak test according to chapter 9.7 of the manual is performed with the help of a test appliance for tightness check, provided by the instrument manufacturer. For this a vacuum is created in the device with the help of the instrument's pump and after switching off the pump, the rise in pressure over a time period of five minutes is monitored. In case of a rise in pressure > 290 hPa, the test on tightness is regarded as failed and the device needs close inspection. The system volume is 215 ml. Furthermore the instrument offers also the leak rate in ml/min as additional information.

The flow rate is 3.3 l/min, i.e. the maximum permissible leak rate is 0.033 l/min or 33 ml/min.

This procedure was finally implemented in the software not before January 2014 and was tested afterwards in the lab.

It is recommended to check the tightness of the measuring system by means of the aforementioned procedure every three months.

6.4 Evaluation

Leakage testing was performed in the laboratory.

The criterion for passing the leakage test, which has been proposed by the manufacturer (maximum pressure increase of 290 hPa in 5 min) proved to be an appropriate parameter for monitoring instrument tightness.

The detected maximum leak rate of 10.4 ml/min is less than 1 % of the nominal flow rate which is 3.3 l/min.

6.5 Assessment

The criterion for passing the leakage test, which has been specified by the manufacturer, (maximum pressure increase of 290 hPa in 5 min) proved to be an appropriate parameter for monitoring instrument tightness. The detected maximum leak rate of 10.4 ml/min is less than 1 % of the nominal flow rate which is 3.3 l/min.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 36 lists the values obtained in leakage testing.

Table 36: Results from leakage testing

Test	SN3		SN4		max. permissible leak rate in ml/min
	Pressure increase in 5 min in hPa	Leak rate in ml/min	Pressure increase in 5 min in hPa	Leak rate in ml/min	
1	108	8.2	151	10.4	33
2	104	8.0	143	10.1	33
3	102	8.0	139	9.9	33

6.1 Methodology of the equivalence check (modules 5.4.9 – 5.4.11)

According to the January 2010 version of the Guide [5], the following 5 criteria shall be met in order to prove equivalence:

1. At least 20 % of the concentration values from the complete dataset (determined by means of reference method) shall exceed the upper assessment threshold for annual limit values determined in 2008/50/EC [8], i.e. 28 µg/m³ for PM₁₀ and 17 µg/m³ for PM_{2.5}.
2. The uncertainty between the candidates must be less than 2.5 µg/m³ for all data and for two sub datasets corresponding to all the data split greater than or equal to and lower than 30 µg/m³ or 18 µg/m³ for PM₁₀ and PM_{2.5} respectively.
3. The uncertainty between the reference devices must be less than 2.0 µg/m³.
4. The expanded uncertainty (W_{CM}) is calculated at 50 µg/m³ for PM₁₀ and 30 µg/m³ for PM_{2.5} for each candidate against the mean value of the reference method. In each of the following cases, the expanded uncertainty shall not exceed 25 %:
 - Full dataset;
 - Dataset with PM concentrations greater/equal 30 µg/m³ for PM₁₀ or greater/equal 18 µg/m³ for PM_{2.5}, provided that the dataset contains 40 or more valid data pairs;
 - Datasets for each field test site.
5. For the complete dataset to be accepted it is required that the slope b differs insignificantly from 1: $|b - 1| \leq 2 \cdot u(b)$ and that the intercept a differs insignificantly from 0: $|a| \leq 2 \cdot u(a)$. Should these requirements not be met, the candidates may be calibrated using the values for slope and/or intercept from the complete dataset.

In the following 5 chapters, compliance with the 5 criteria is tested:

In chapter 6.1 5.4.9 Determination of uncertainty between systems under test u_{bs} criteria 1 and 2 will be checked.

In chapter 6.1 5.4.10 Calculation of expanded uncertainty between systems under test criteria 3, 4, and 5 will be checked.

In chapter 6.1 5.4.11 Application of correction factors and terms there is an exemplary evaluation for the event that criterion 5 cannot be met without application of correction factors or terms.

6.1 5.4.9 Determination of uncertainty between systems under test u_{bs}

For the test of PM_{2.5} measuring systems the uncertainty between the systems under test shall be determined according to chapter 9.5.3.1 of the Guide "Demonstration of equivalence of Ambient Air Monitoring Methods" in the field test at least at four sampling sites representative of the future application.

The tests were also carried out for the component PM₁₀.

6.2 Equipment

No equipment is necessary to test this performance criterion.

6.3 Method

The test was carried out at four different comparisons during the field test. Different seasons and varying concentrations for PM_{2.5} and PM₁₀ were taken into consideration.

At least 20 % of the concentration values from the complete dataset determined with the reference method shall exceed the upper assessment threshold according to 2008/50/EC [8]. The upper assessment threshold is 17 µg/m³ for PM_{2.5} and 28 µg/m³ for PM₁₀.

At least 40 valid data pairs were determined per comparison. Out of the complete dataset (4 test sites, PM₁₀: 195 valid data pairs for SN3 and 193 valid data pairs for SN4; PM_{2.5}: 194 valid data pairs for SN3 and 192 valid data pairs for SN4), 28.6 % of the measured values exceed the upper assessment threshold of 17 µg/m³ for PM_{2.5} and a total of 20.7 % of the measured values exceed the upper assessment threshold of 28 µg/m³ for PM₁₀. The measured concentrations were brought into relation with ambient conditions.

6.4 Evaluation

According to **chapter 9.5.3.1** of the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods" the following applies:

The uncertainty between the candidates u_{bs} shall be ≤ 2.5 µg/m³. If the uncertainty between the candidates exceeds 2.5 µg/m³, one or both systems might not be working properly. In such a case, equivalence cannot be declared.

Uncertainty is determined for:

- All test sites/comparisons together (full dataset)
- 1 dataset with measured values ≥ 18 µg/m³ for PM_{2.5} (basis: mean values of reference measurement)
- 1 dataset with measured values ≥ 30 µg/m³ for PM₁₀ (basis: mean values of reference measurement)

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In addition to that, this report provides an evaluation of the following datasets:

- Each test site/comparison separately
- 1 dataset with measured values < 18 µg/m³ for PM_{2.5} (basis: mean values of reference measurement)
- 1 dataset with measured values < 30 µg/m³ for PM₁₀ (basis: mean values of reference measurement)

The uncertainty between the candidates u_{bs} is calculated from the differences of all daily mean values (24 h values) of the simultaneously operated candidates by means of the following equation:

$$u_{bs}^2 = \frac{\sum_{i=1}^n (y_{i,1} - y_{i,2})^2}{2n}$$

with $y_{i,1}$ and $y_{i,2}$ = results of the parallel measurements of individual 24 h values i
 n = number of 24 h values

6.5 Assessment

The uncertainty between the candidates u_{bs} with a maximum of 1.04 µg/m³ for PM_{2.5} and a maximum of 2.28 µg/m³ for PM₁₀ does not exceed the required value of 2.5 µg/m³.

Performance criterion met? yes

6.6 Detailed presentation of test results

Table 37 and Table 38 list the calculated values for the uncertainty between candidates u_{bs} . Graphical representations of the results are provided in Figure 53 to Figure 66.

Table 37: Uncertainty between candidates u_{bs} for the devices SN3 and SN4, measured component PM_{2.5}

Device	Test site	No. of values	Uncertainty u_{bs}
SN			$\mu\text{g}/\text{m}^3$
SN3 / SN4	All test sites	237	0.65
Single test sites			
SN3 / SN4	Cologne, summer	69	0.65
SN3 / SN4	Cologne, winter	61	0.88
SN3 / SN4	Bonn, winter	54	0.57
SN3 / SN4	Rodenkirchen, summer	53	0.33
Classification over reference value			
SN3 / SN4	Values $\geq 18 \mu\text{g}/\text{m}^3$	49	1.04
SN3 / SN4	Values $< 18 \mu\text{g}/\text{m}^3$	143	0.42

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Table 38: *Uncertainty between candidates u_{bs} for the devices SN3 and SN4, measured component PM₁₀*

Device	Test site	No. of values	Uncertainty u_{bs}
SN			$\mu\text{g}/\text{m}^3$
SN3 / SN4	All test sites	237	1.27
Single test sites			
SN3 / SN4	Cologne, summer	69	1.38
SN3 / SN4	Cologne, winter	61	1.72
SN3 / SN4	Bonn, winter	54	1.06
SN3 / SN4	Rodenkirchen, summer	53	0.43
Classification over reference values			
SN3 / SN4	Values $\geq 30 \mu\text{g}/\text{m}^3$	33	2.28
SN3 / SN4	Values $< 30 \mu\text{g}/\text{m}^3$	160	0.96

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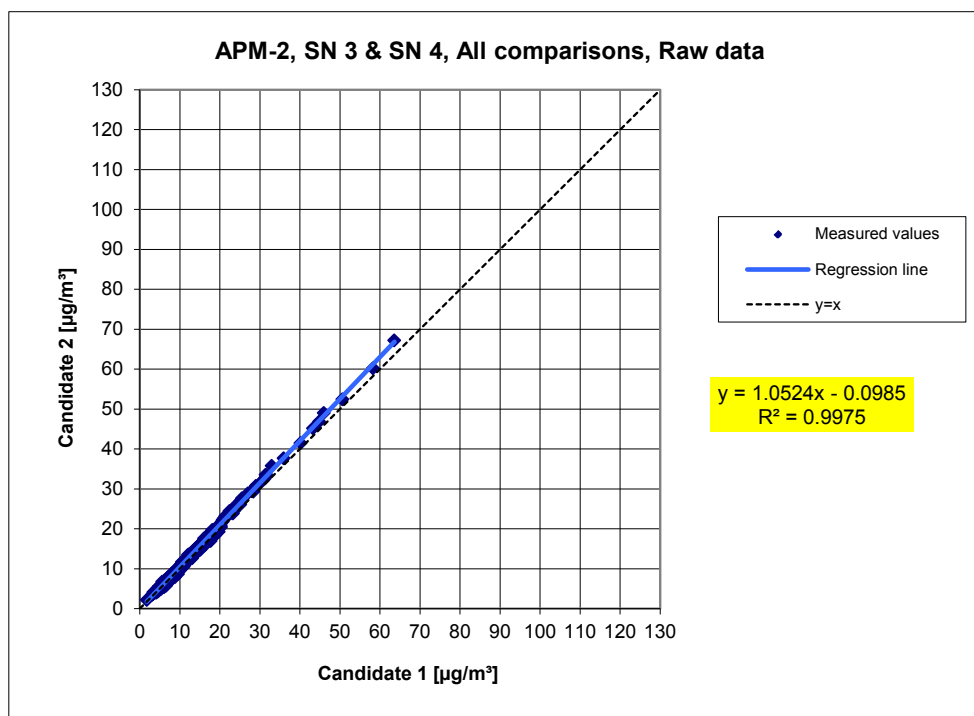


Figure 53: Results of the parallel measurements with the devices SN3 / SN4, measured component PM_{2.5}, all test sites

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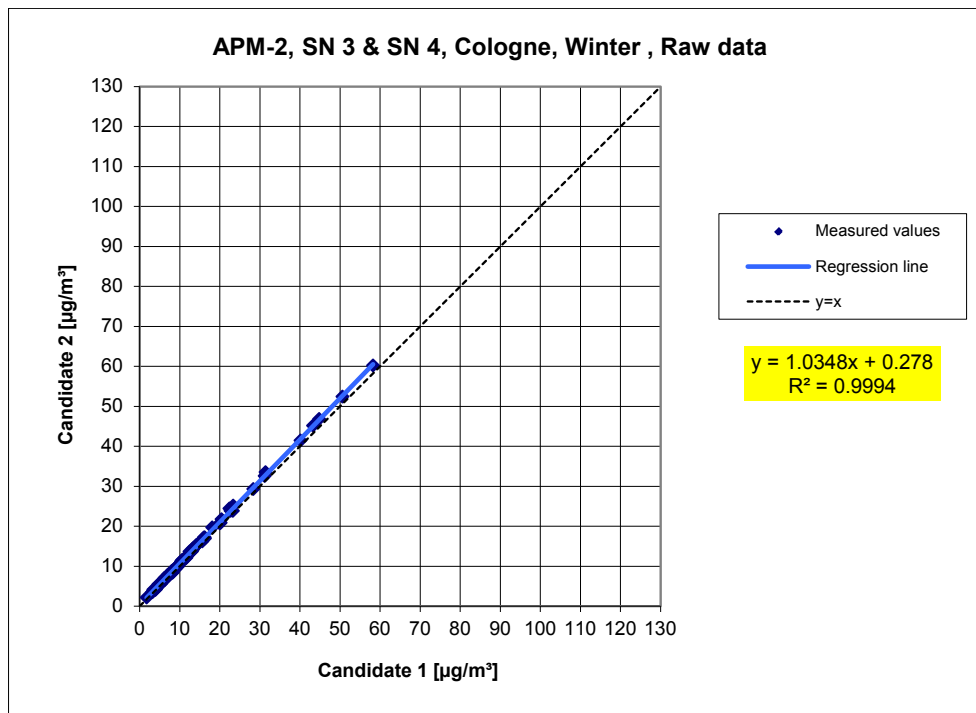


Figure 54: Results of the parallel measurements with the devices SN3 / SN4, measured component PM_{2.5}, test site Cologne, winter

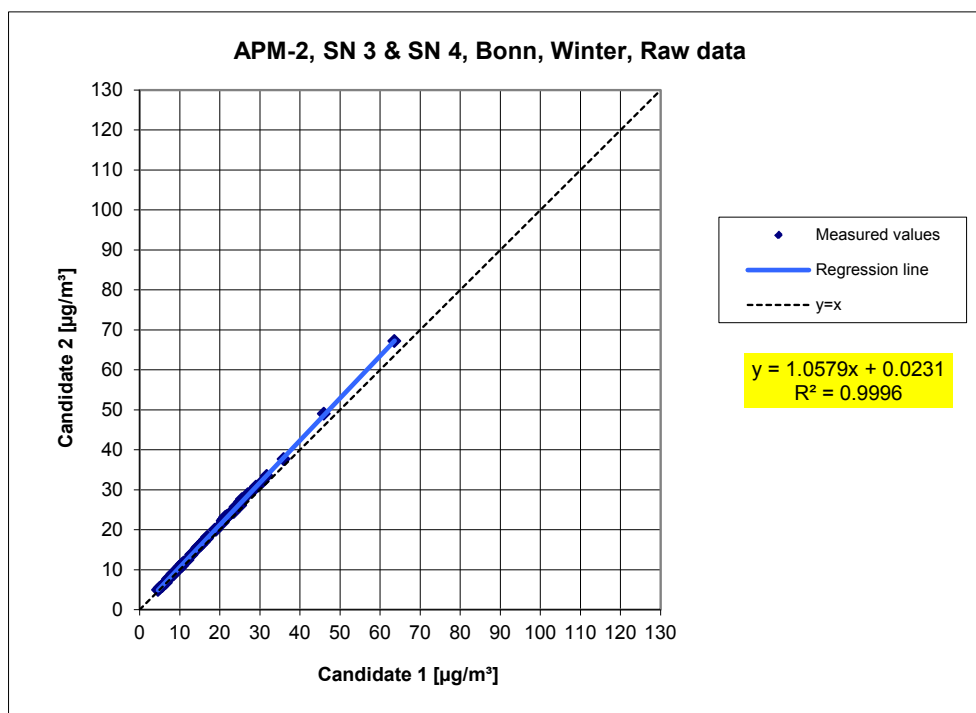


Figure 55: Results of the parallel measurements with the devices SN3 / SN4, measured component PM_{2.5}, test site Bonn, winter

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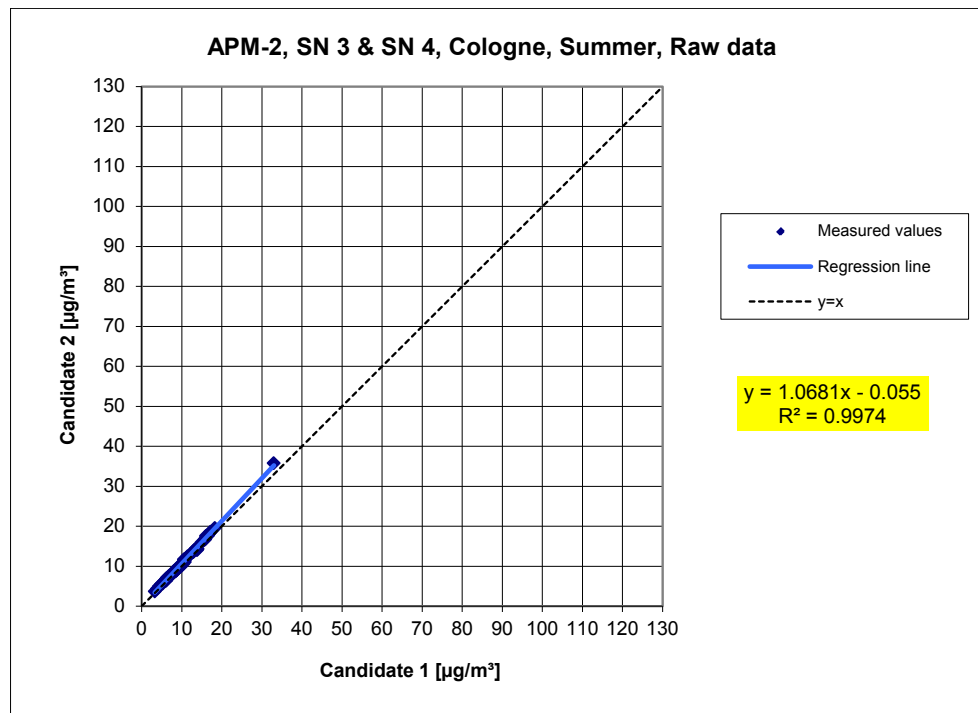


Figure 56: Results of the parallel measurements with the devices SN3 / SN4, measured component PM_{2.5}, test site Cologne, summer

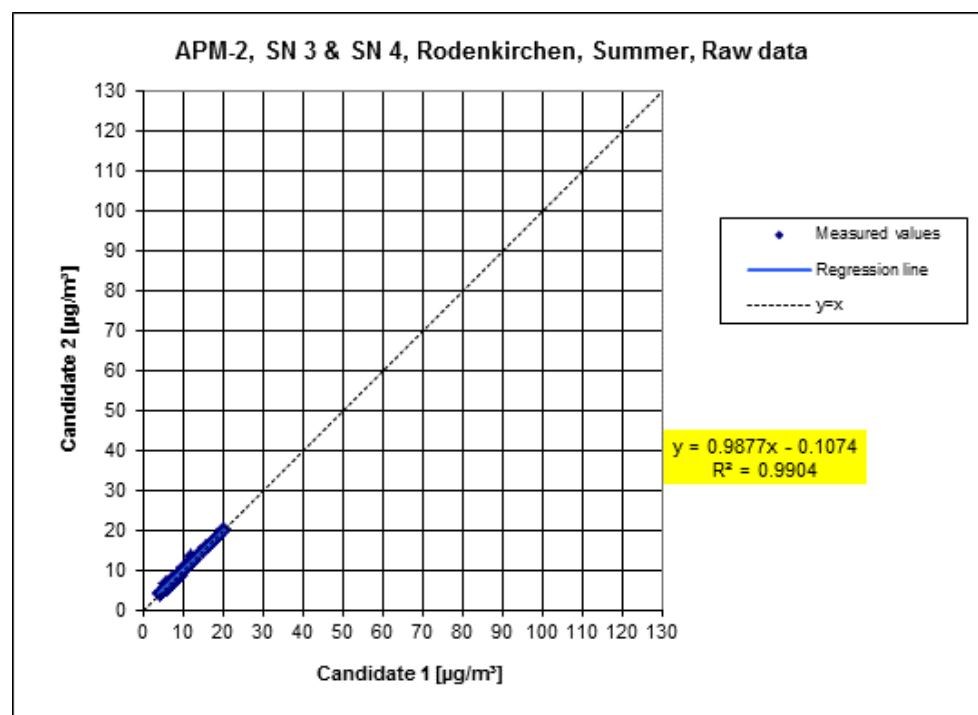


Figure 57: Results of the parallel measurements with the devices SN3 / SN4, measured component PM_{2.5}, test site Rodenkirchen, summer

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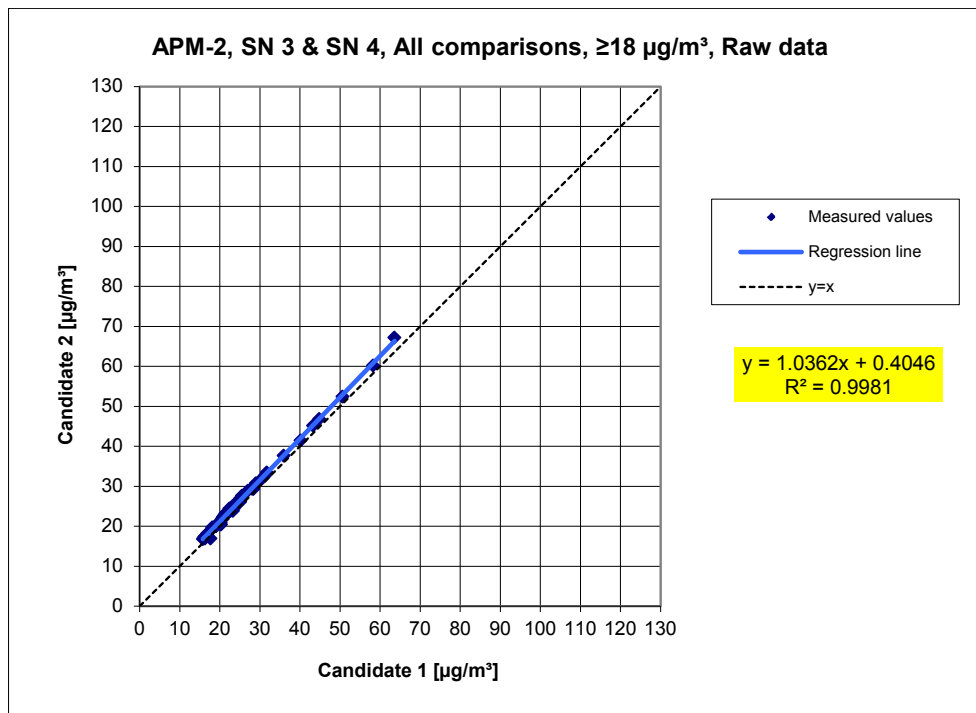


Figure 58: Results of the parallel measurements with the devices SN3 / SN4, measured component PM_{2.5}, all test sites, values $\geq 18 \mu\text{g}/\text{m}^3$

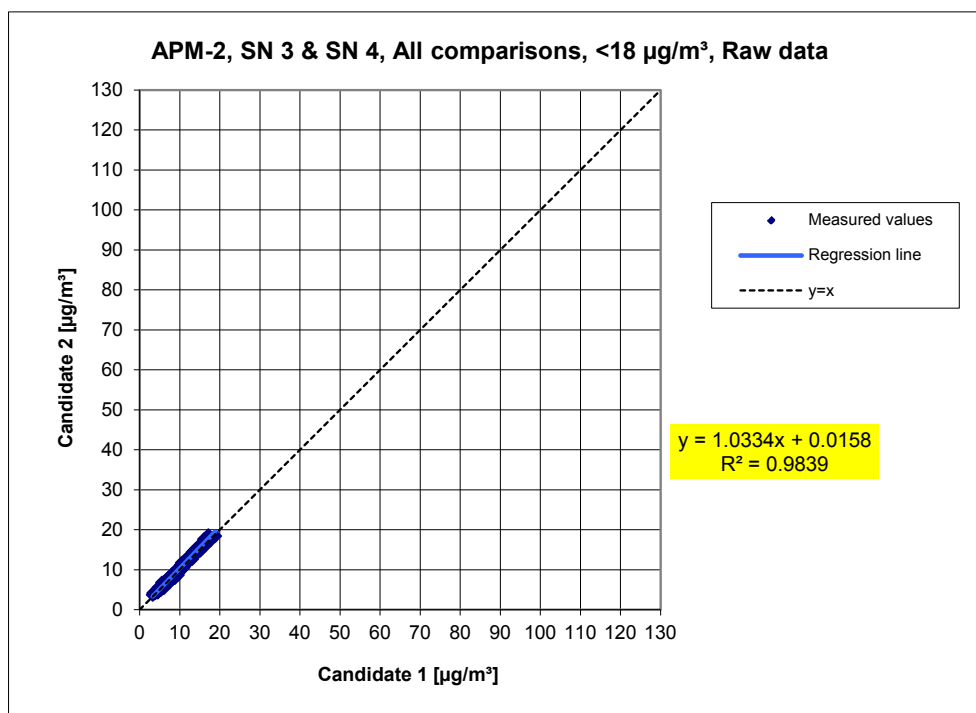


Figure 59: Results of the parallel measurements with the devices SN3 / SN4, measured component PM_{2.5}, all test sites, values $< 18 \mu\text{g}/\text{m}^3$

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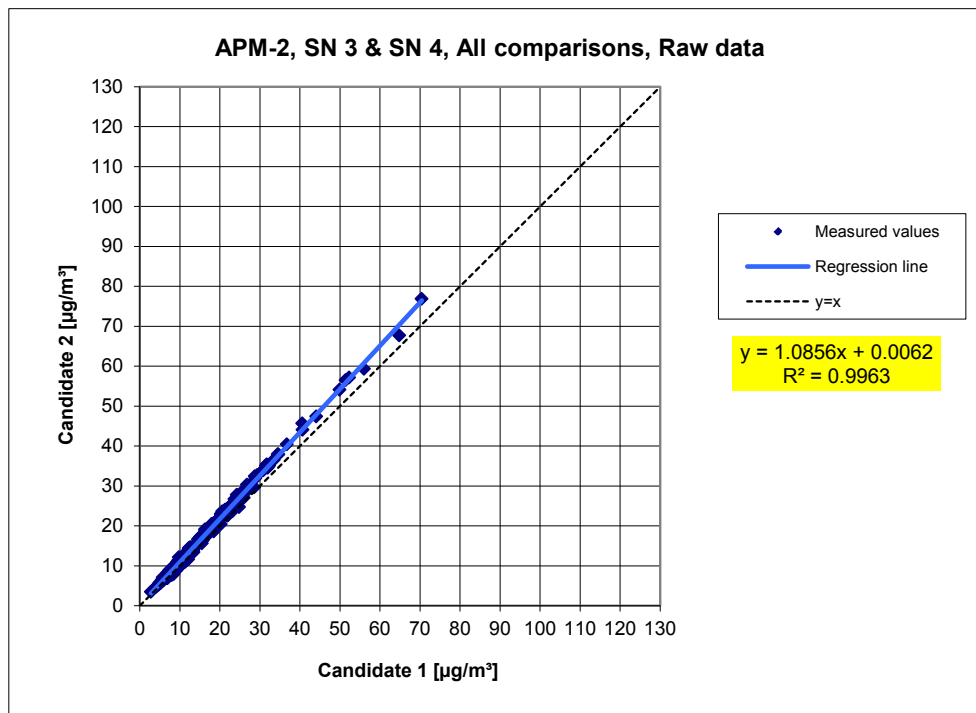


Figure 60: Results of the parallel measurements with the devices SN3 / SN4, measured component PM₁₀, all test sites

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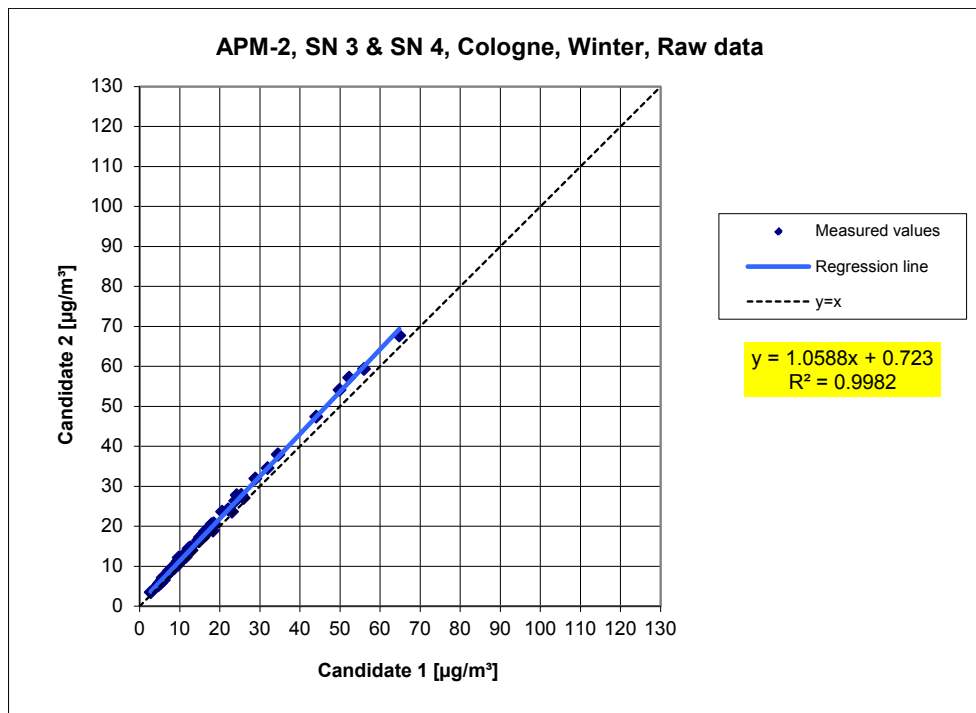


Figure 61: Results of the parallel measurements with the devices SN3 / SN4, measured component PM₁₀, test site Cologne, winter

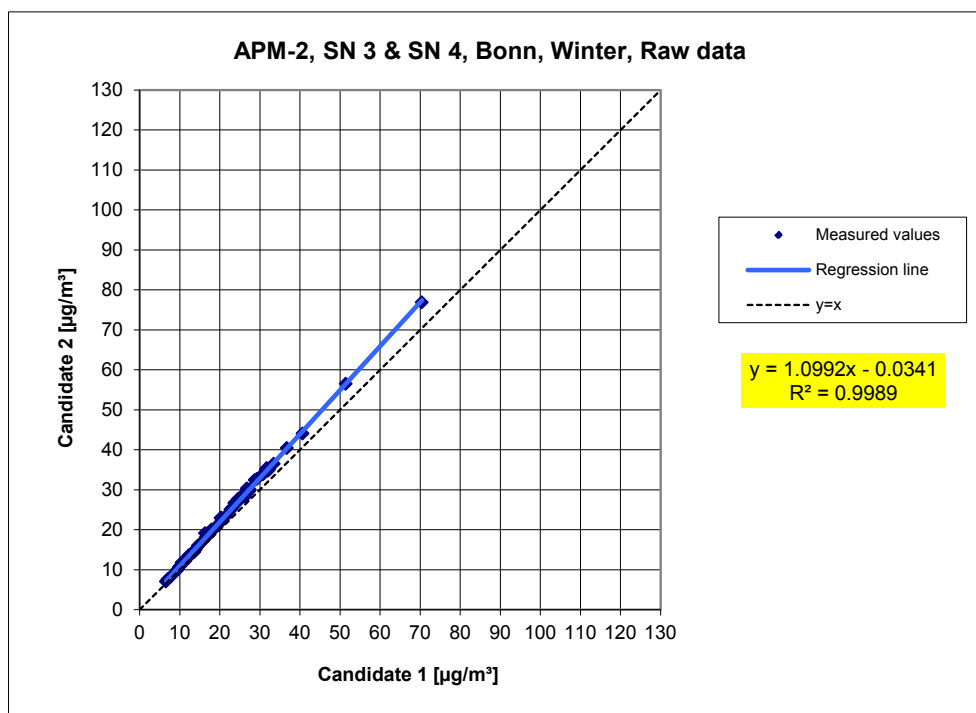


Figure 62: Results of the parallel measurements with the devices SN3 / SN4, measured component PM₁₀, test site Bonn, winter

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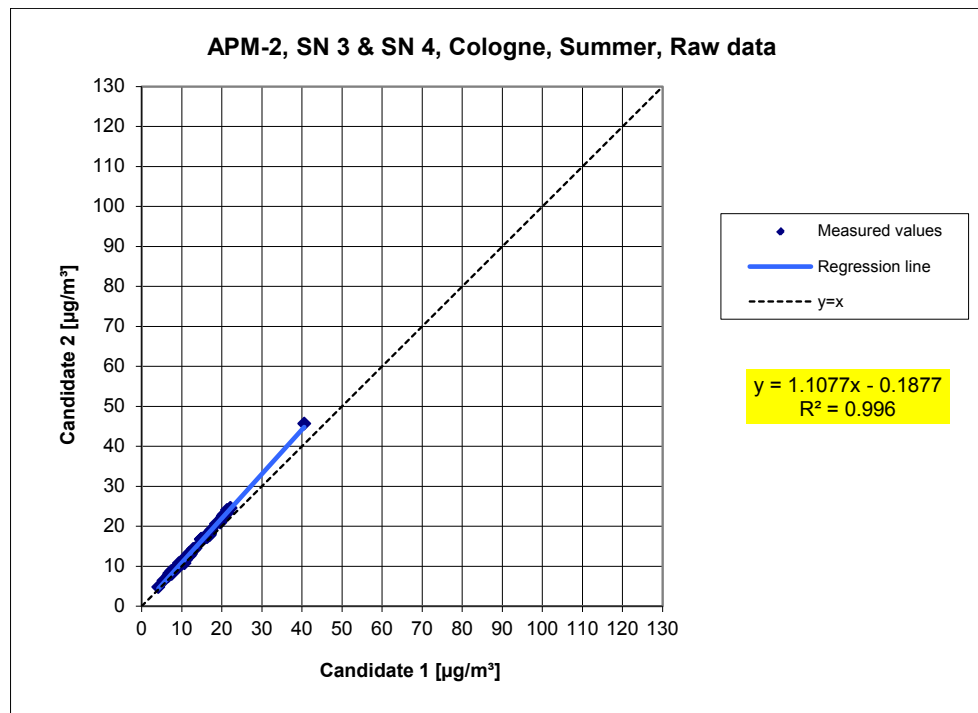


Figure 63: Results of the parallel measurements with the devices SN3 / SN4, measured component PM₁₀, test site Cologne, summer

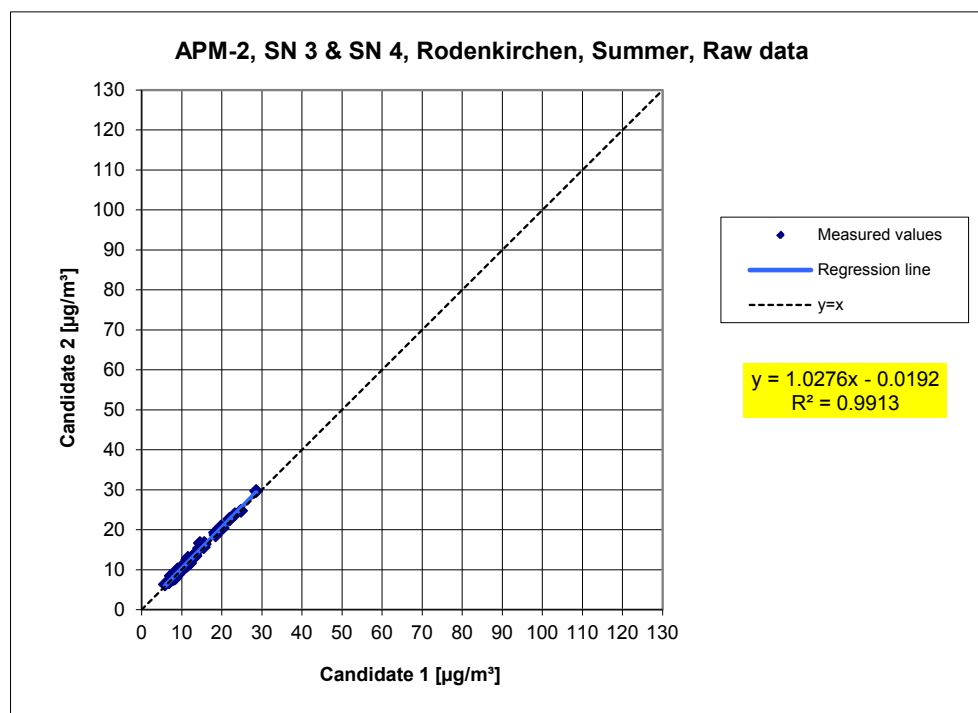


Figure 64: Results of the parallel measurements with the devices SN3 / SN4, measured component PM₁₀, test site Rodenkirchen, summer

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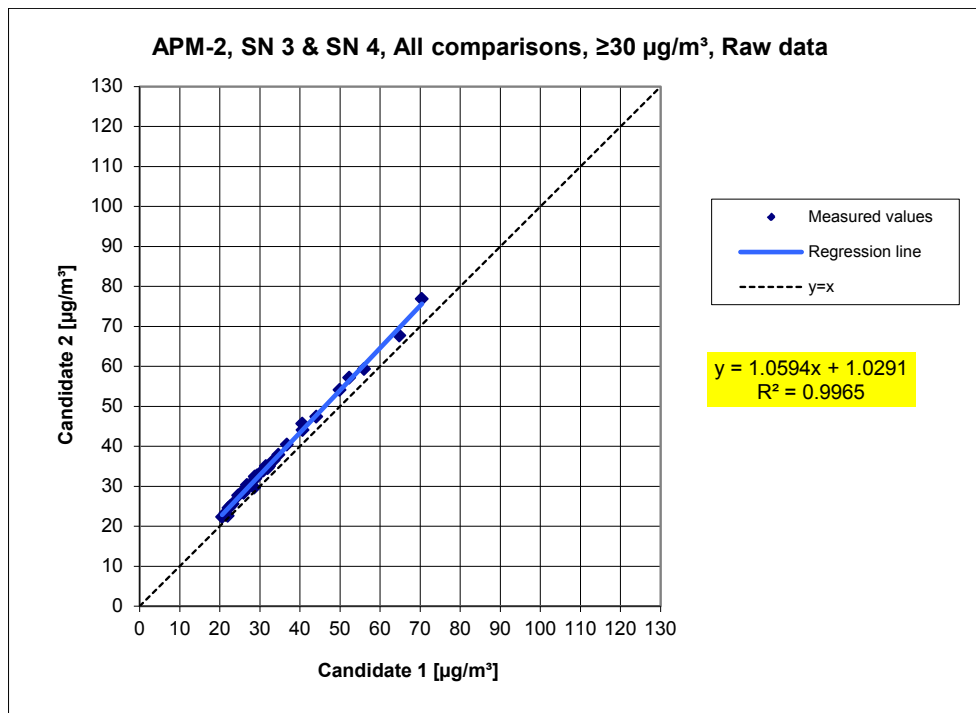


Figure 65: Results of the parallel measurements with the devices SN3 / SN4, measured component PM₁₀, all test sites, values $\geq 30 \mu\text{g}/\text{m}^3$

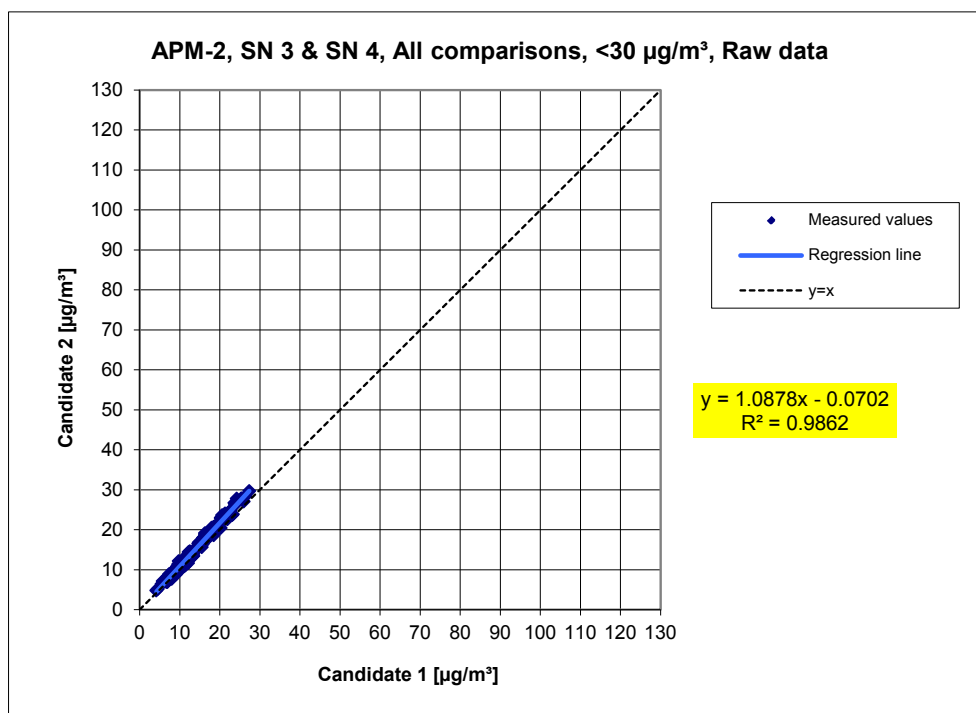


Figure 66: Results of the parallel measurements with the devices SN3 / SN4, measured component PM₁₀, all test sites, values $< 30 \mu\text{g}/\text{m}^3$

6.1 5.4.10 Calculation of expanded uncertainty between systems under test

For the test of PM_{2.5} measuring systems the equivalency with reference method shall be demonstrated according to chapter 9.5.3.2 to 9.6 of the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods" in the field test at least at four sampling sites representative of the future application. The maximum expanded uncertainty of the systems under test shall be compared with data quality objectives to Annex A of VDI Standard 4202, Sheet 1 (September 2010).

The tests were also carried out for the component PM₁₀.

6.2 Equipment

Additional instruments according to item 5 of this report were used in the testing of this performance criterion.

6.3 Method

The test was carried out at four different comparisons during the field test. Different seasons and varying concentrations for PM_{2.5} and PM₁₀ were taken into consideration.

At least 20 % of the concentration values from the complete dataset determined with the reference method shall exceed the upper assessment threshold according to 2008/50/EC [8]. The upper assessment threshold is 17 µg/m³ for PM_{2.5} and 28 µg/m³ for PM₁₀.

At least 40 valid data pairs were determined per comparison. Out of the complete dataset (4 test sites, PM₁₀: 195 valid data pairs for SN3 and 193 valid data pairs for SN4; PM_{2.5}: 194 valid data pairs for SN3 and 192 valid data pairs for SN4), 28.6 % of the measured values exceed the upper assessment threshold of 17 µg/m³ for PM_{2.5} and a total of 20.7 % of the measured values exceed the upper assessment threshold of 28 µg/m³ for PM₁₀. The measured concentrations were brought into relation with ambient conditions.

6.4 Evaluation

[Item 9.5.3.2] The calculation of expanded uncertainty is preceded by an uncertainty check between the two simultaneously operated reference devices u_{ref} .

The uncertainty between the simultaneously operated reference devices is determined analogous to the uncertainty between the candidates and shall be $\leq 2 \mu\text{g}/\text{m}^3$.

The evaluated results are given in 7.6 of this test item.

In order to evaluate the comparability between the candidates y and the reference method x , a linear correlation $y_i = a + bx_i$ between the measured results obtained from both methods is assumed. The correlation between the mean values of the reference devices and the candidates, which shall be assessed individually, is established by means of orthogonal regression.

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Regression is calculated for:

- All test sites/comparisons together
- Each test site/comparison separately
- 1 dataset with measured values $\geq 18 \mu\text{g}/\text{m}^3$ for PM_{2.5} (basis: mean values of reference measurement)
- 1 dataset with measured values $\geq 30 \mu\text{g}/\text{m}^3$ for PM₁₀ (basis: mean values of reference measurement)

For further evaluation, the results of the uncertainty $u_{c,s}$ of the candidates compared with the reference method is described in the following equation, which describes u_{CR} as a function of the OM concentration x_i .

$$u_{CR}^2(y_i) = \frac{RSS}{(n-2)} - u^2(x_i) + [a + (b-1)x_i]^2$$

With RSS = Sum of the (relative) residuals from orthogonal regression

$u(x_i)$ = random uncertainty of the reference procedure, if the value u_{bs} , which is calculated for using the candidates, can be used in this test (refer to item 6.1 5.4.9 Determination of uncertainty between systems under test u_{bs})

Algorithms for the calculation of intercept a as well as slope b and its variances by means of orthogonal regression are specified in Annex B of [5].

The sum of the (relative) residuals RSS is calculated using the following equation:

$$RSS = \sum_{i=1}^n (y_i - a - bx_i)^2$$

Uncertainty u_{CR} is calculated for:

- All test sites/comparisons together
- Each test site/comparison separately
- 1 dataset with measured values $\geq 18 \mu\text{g}/\text{m}^3$ for PM_{2.5} (basis: mean values of reference measurement)
- 1 dataset with measured values $\geq 30 \mu\text{g}/\text{m}^3$ for PM₁₀ (basis: mean values of reference measurement)

According to the Guide, preconditions for acceptance of the full dataset are that:

- the slope b differs insignificantly from 1: $|b - 1| \leq 2 \cdot u(b)$

and that

- the intercept a differs insignificantly from 0: $|a| \leq 2 \cdot u(a)$

with $u(b)$ and $u(a)$ being the standard uncertainties of slope and intercept, each calculated as the square root of their variances. If these preconditions are not met, the candidates may be calibrated according to item 9.7 of the guideline (refer to 6.1 5.4.11 Application of correction factors and terms. The calibration shall only be applied to the full dataset.

[Item 9.5.4] The combined uncertainty of the candidates $w_{c,CM}$ is calculated for each dataset by combining the contributions from 9.5.3.1 and 9.5.3.2 according to the following equation:

$$w_{c,CM}^2(y_i) = \frac{u_{CR}^2(y_i)}{y_i^2}$$

For each dataset, the uncertainty $w_{c,CM}$ is calculated at the level of $y_i = 30 \mu\text{g}/\text{m}^3$ for PM_{2.5} and at the level of $y_i = 50 \mu\text{g}/\text{m}^3$ for PM₁₀.

[Item 9.5.5] The expanded relative uncertainty of the results of the candidates is calculated for each dataset by multiplying $w_{c,CM}$ with a coverage factor k according to the following equation:

$$W_{CM} = k \cdot w_{CM}$$

In praxis $k=2$ for large n

[Item 9.6] The highest resulting uncertainty W_{CM} is compared with the requirements on data quality of ambient air measurements according to EU Standard [8] and assessed. There are two possible results:

1. $W_{CM} \leq W_{dgo}$ → Candidate method is considered equivalent to the reference method
2. $W_{CM} > W_{dgo}$ → Candidate method is considered not equivalent to the reference method

The specified expanded relative uncertainty W_{dgo} for particulate matter is 25 % [8].

6.5 Assessment

Without application of correction factors, the determined uncertainties W_{CM} for PM_{2.5} for all datasets under consideration lie below the defined expanded relative uncertainty W_{dgo} of 25 % for suspended particulate matter.

Without application of correction factors, the determined uncertainties W_{CM} for PM₁₀ for SN3 are for all datasets above the defined expanded relative uncertainty W_{dgo} of 25 % with exception of Cologne, Winter, for SN4 the data set Rodenkirchen, Summer and for both candidates together the data set $\geq 30 \mu\text{g}/\text{m}^3$ are also above the defined expanded relative uncertainty W_{dgo} of 25 % for suspended particulate matter.

Correction factors shall be applied according to chapter 6.1 5.4.11 Application of correction factors and terms.

Performance criterion met? no

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Table 39 and Table 40 provide an overview of all results from the equivalence test of the APM-2 for PM_{2.5} and PM₁₀. In the event that a criterion has not been met, the respective cell is marked in yellow.

Table 39: Overview of equivalence test of APM-2 for PM_{2.5}

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010				
Candidate	APM-2	SN	SN 3 & SN 4	
Status of measured values	Raw data	Limit value	30	µg/m³
		Allowed uncertainty	25	%
All comparisons				
Uncertainty between Reference	0.55			µg/m³
Uncertainty between Candidates	0.65			µg/m³
SN 3 & SN 4				
Number of data pairs	192			
Slope b	0.919			significant
Uncertainty of b	0.012			
Ordinate intercept a	0.327			not significant
Uncertainty of a	0.216			
Expanded meas. uncertainty W _{CM}	17.68			%
All comparisons, ≥18 µg/m³				
Uncertainty between Reference	0.63			µg/m³
Uncertainty between Candidates	1.04			µg/m³
SN 3 & SN 4				
Number of data pairs	49			
Slope b	0.887			
Uncertainty of b	0.030			
Ordinate intercept a	1.248			
Uncertainty of a	0.937			
Expanded meas. uncertainty W _{CM}	21.92			%
All comparisons, <18 µg/m³				
Uncertainty between Reference	0.53			µg/m³
Uncertainty between Candidates	0.42			µg/m³
SN 3 & SN 4				
Number of data pairs	143			
Slope b	1.040			
Uncertainty of b	0.030			
Ordinate intercept a	-0.928			
Uncertainty of a	0.327			
Expanded meas. uncertainty W _{CM}	7.98			%

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Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010				
Candidate	APM-2	SN	SN 3 & SN 4	
Status of measured values	Raw data	Limit value	30	µg/m³
		Allowed uncertainty	25	%
Cologne, Winter				
Uncertainty between Reference	0.54	µg/m³		
Uncertainty between Candidates	0.65	µg/m³		
	SN 3		SN 4	
Number of data pairs	52		52	
Slope b	0.855		0.883	
Uncertainty of b	0.017		0.018	
Ordinate intercept a	1.068		1.387	
Uncertainty of a	0.389		0.400	
Expanded meas. uncertainty W _{CM}	24.56	%	18.11	%
Bonn, Winter				
Uncertainty between Reference	0.62	µg/m³		
Uncertainty between Candidates	0.88	µg/m³		
	SN 3		SN 4	
Number of data pairs	51		51	
Slope b	0.952		1.007	
Uncertainty of b	0.029		0.029	
Ordinate intercept a	-0.834		-0.849	
Uncertainty of a	0.649		0.666	
Expanded meas. uncertainty W _{CM}	20.54	%	14.80	%
Cologne, Summer				
Uncertainty between Reference	0.53	µg/m³		
Uncertainty between Candidates	0.57	µg/m³		
	SN 3		SN 4	
Number of data pairs	46		44	
Slope b	0.966		1.019	
Uncertainty of b	0.041		0.045	
Ordinate intercept a	-0.221		-0.174	
Uncertainty of a	0.453		0.508	
Expanded meas. uncertainty W _{CM}	10.59	%	7.90	%
Rodenkirchen, Summer				
Uncertainty between Reference	0.52	µg/m³		
Uncertainty between Candidates	0.33	µg/m³		
	SN 3		SN 4	
Number of data pairs	45		45	
Slope b	1.053		1.037	
Uncertainty of b	0.046		0.047	
Ordinate intercept a	-1.230		-1.320	
Uncertainty of a	0.519		0.521	
Expanded meas. uncertainty W _{CM}	7.76	%	7.54	%
All comparisons, ≥18 µg/m³				
Uncertainty between Reference	0.63	µg/m³		
Uncertainty between Candidates	1.04	µg/m³		
	SN 3		SN 4	
Number of data pairs	49		49	
Slope b	0.871		0.904	
Uncertainty of b	0.030		0.031	
Ordinate intercept a	1.046		1.438	
Uncertainty of a	0.921		0.96	
Expanded meas. uncertainty W _{CM}	24.98	%	19.63	%
All comparisons, <18 µg/m³				
Uncertainty between Reference	0.53	µg/m³		
Uncertainty between Candidates	0.42	µg/m³		
	SN 3		SN 4	
Number of data pairs	145		143	
Slope b	1.019		1.065	
Uncertainty of b	0.029		0.031	
Ordinate intercept a	-0.877		-1.020	
Uncertainty of a	0.317		0.344	
Expanded meas. uncertainty W _{CM}	7.80	%	10.37	%
All comparisons				
Uncertainty between Reference	0.55	µg/m³		
Uncertainty between Candidates	0.65	µg/m³		
	SN 3		SN 4	
Number of data pairs	194		192	
Slope b	0.896	significant	0.943	significant
Uncertainty of b	0.012		0.012	
Ordinate intercept a	0.382	not significant	0.267	not significant
Uncertainty of a	0.209		0.225	
Expanded meas. uncertainty W _{CM}	21.09	%	14.84	%

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The results of the check of the five criteria given in chapter 6.1 Methodology of the equivalence check (modules 5.4.9 – 5.4.11) are as follows:

- Criterion 1: More than 20 % of the data are greater than 17 µg/m³.
- Criterion 2: The uncertainty between the candidates is less than 2.5 µg/m³.
- Criterion 3: The uncertainty between the reference devices is less than 2.0 µg/m³.
- Criterion 4: All expanded uncertainties are below 25 %.
- Criterion 5: The slopes for evaluation of the complete dataset are significantly greater than the permissible values for both devices.
- Other: For both candidates together, the slope is 0.919 and the intercept is 0.327 at an expanded overall uncertainty of 17.68 % for the full dataset.

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Table 40: Overview of equivalence test of APM-2 for PM₁₀

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010				
Candidate	APM-2	SN	SN 3 & SN 4	
Status of measured values	Raw data	Limit value	50	µg/m³
		Allowed uncertainty	25	%
All comparisons				
Uncertainty between Reference	0.58			µg/m³
Uncertainty between Candidates	1.27			µg/m³
SN 3 & SN 4				
Number of data pairs	193			
Slope b	0.977			nicht signifikant
Uncertainty of b	0.020			
Ordinate intercept a	-3.758			signifikant
Uncertainty of a	0.502			
Expanded measured uncertainty WCM	23.25			%
All comparisons, ≥30 µg/m³				
Uncertainty between Reference	0.72			µg/m³
Uncertainty between Candidates	2.28			µg/m³
SN 3 & SN 4				
Number of data pairs	33			
Slope b	1.035			
Uncertainty of b	0.063			
Ordinate intercept a	-6.432			
Uncertainty of a	2.681			
Expanded measured uncertainty WCM	25.88			%
All comparisons, <30 µg/m³				
Uncertainty between Reference	0.55			µg/m³
Uncertainty between Candidates	0.96			µg/m³
SN 3 & SN 4				
Number of data pairs	160			
Slope b	0.971			
Uncertainty of b	0.040			
Ordinate intercept a	-3.579			
Uncertainty of a	0.751			
Expanded measured uncertainty WCM	23.05			%

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Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010				
Candidate	APM-2	SN	SN 3 & SN 4	
Status of measured values	Raw data	Limit value	50	µg/m³
		Allowed uncertainty	25	%
Cologne, Winter				
Uncertainty between Reference	0.54	µg/m³		
Uncertainty between Candidates	1.38	µg/m³		
	SN 3		SN 4	
Number of data pairs	52		52	
Slope b	0.931		0.982	
Uncertainty of b	0.023		0.022	
Ordinate intercept a	-2.007		-1.290	
Uncertainty of a	0.611		0.582	
Expanded measured uncertainty W _{CM}	23.70	%	12.30	%
Bonn, Winter				
Uncertainty between Reference	0.38	µg/m³		
Uncertainty between Candidates	1.72	µg/m³		
	SN 3		SN 4	
Number of data pairs	51		51	
Slope b	0.943		1.043	
Uncertainty of b	0.049		0.054	
Ordinate intercept a	-4.224		-4.829	
Uncertainty of a	1.477		1.604	
Expanded measured uncertainty W _{CM}	32.57	%	20.66	%
Cologne, Summer				
Uncertainty between Reference	0.60	µg/m³		
Uncertainty between Candidates	1.06	µg/m³		
	SN 3		SN 4	
Number of data pairs	47		45	
Slope b	0.852		0.954	
Uncertainty of b	0.039		0.043	
Ordinate intercept a	-1.667		-2.156	
Uncertainty of a	0.733		0.809	
Expanded measured uncertainty W _{CM}	36.90	%	19.49	%
Rodenkirchen, Summer				
Uncertainty between Reference	0.76	µg/m³		
Uncertainty between Candidates	0.43	µg/m³		
	SN 3		SN 4	
Number of data pairs	45		45	
Slope b	0.944		0.983	
Uncertainty of b	0.063		0.063	
Ordinate intercept a	-5.390		-5.818	
Uncertainty of a	1.252		1.258	
Expanded measured uncertainty W _{CM}	33.83	%	28.11	%
All comparisons, ≥30 µg/m³				
Uncertainty between Reference	0.72	µg/m³		
Uncertainty between Candidates	2.28	µg/m³		
	SN 3		SN 4	
Number of data pairs	33		33	
Slope b	1.003		1.068	
Uncertainty of b	0.062		0.065	
Ordinate intercept a	-6.650		-6.252	
Uncertainty of a	2.639		2.74	
Expanded measured uncertainty W _{CM}	31.43	%	21.54	%
All comparisons, <30 µg/m³				
Uncertainty between Reference	0.55	µg/m³		
Uncertainty between Candidates	0.96	µg/m³		
	SN 3		SN 4	
Number of data pairs	162		160	
Slope b	0.921		1.025	
Uncertainty of b	0.037		0.043	
Ordinate intercept a	-3.223		-4.000	
Uncertainty of a	0.698		0.807	
Expanded measured uncertainty W _{CM}	30.60	%	16.42	%
All comparisons				
Uncertainty between Reference	0.58	µg/m³		
Uncertainty between Candidates	1.27	µg/m³		
	SN 3		SN 4	
Number of data pairs	195		193	
Slope b	0.935	signifikant	1.020	nicht signifikant
Uncertainty of b	0.019		0.022	
Ordinate intercept a	-3.552	signifikant	-3.981	signifikant
Uncertainty of a	0.474		0.531	
Expanded measured uncertainty W _{CM}	29.69	%	17.80	%

The results of the check of the five criteria given in chapter 6.1 Methodology of the equivalence check (modules 5.4.9 – 5.4.11) are as follows:

- Criterion 1: More than 20 % of the data are greater than 28 µg/m³.
- Criterion 2: The uncertainty between the candidates is less than 2.5 µg/m³.
- Criterion 3: The uncertainty between the reference devices is less than 2.0 µg/m³.
- Criterion 4: For SN3 all of the expanded uncertainties are above 25 % with the exception of Cologne, winter.
For SN4 all of the expanded uncertainties are below 25 % with the exception of Rodenkirchen, summer.
For SN3 and SN4 together, the expanded uncertainty for the data set ≥ 30 µg/m³ is above 25 %.
- Criterion 5: For SN3 the slope as well as the intercept of the evaluation of the full dataset are significantly greater than the permissible values.
For SN4 the intercept of the evaluation of the full dataset is significantly greater than the permissible values.
- Other: For both candidates, the total slope is 0.977 and the intercept is -3.758 at an expanded overall uncertainty of 23.25 % for the full dataset.

The January 2010 version of the Guide is ambiguous with respect to which slope and which intercept should be used to correct a candidate should it fail the test of equivalence. After consultation with the convenor (Mr Theo Hafkenscheid) of the EC working group responsible for setting up the Guide, it was decided that the requirements of the November 2005 version of the Guide are still valid, and that the slope and intercept from the orthogonal regression of all the paired data be used. These are stated additionally under “Other” in the above.

The 2006 UK Equivalence Report [10] has highlighted this was a flaw in the mathematics required for equivalence as per the November 2005 version of the Guide as it penalized instruments that were more accurate (Annex E Section 4.2 therein). This same flaw is copied in the January 2010 version. It is proposed that the same pragmatic approach is taken here that was previously undertaken in earlier studies.

Therefore, according to Table 39, the slope must be corrected for PM_{2.5} due to the determined significance. For PM₁₀, the slope and intercept must be corrected due to exceedance of the permissible expanded uncertainty for several comparison campaigns and due to the determined significance according to Table 40. Nonetheless it should be noted that, even without application of correction factors, the determined uncertainties W_{CM} for PM_{2.5} lie below the specified expanded relative uncertainty $W_{d,qo}$ of 25 % for particulate matter for all datasets considered.

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For PM_{2.5}:

The slope for the complete dataset is 0.919. Thus, an additional evaluation applying the respective calibration factors to the datasets is made in chapter 6.1 5.4.11 Application of correction factors and terms.

For PM₁₀:

The slope for the complete dataset is 0.977. The intercept for the complete dataset is -3.758. An additional evaluation where the respective calibration factors are applied to the datasets is made in chapter 6.1 5.4.11 Application of correction factors and terms.

The revised January 2010 version of the Guide requires that, in order to monitor the processes in compliance with the guidelines, random checks shall be performed on a number of systems within a measuring network and that the number of measuring sites shall depend on the expanded uncertainty of the system. Either the network operator or the responsible authority of the member state is responsible for the appropriate realization of the requirement mentioned above. However, TÜV Rheinland recommends that the expanded uncertainty for the full dataset (here: uncorrected raw data) shall be referred to, i.e. 17.68 % for PM_{2.5}, which would require annual checks at 4 sites, and 23.25 %, for PM₁₀, which would require annual checks a 5 sites (Guide [5], Chapter 9.9.2, Table 6). Due to the necessary application of the corresponding calibration factors, this assessment should be made on the basis of the evaluation of the corrected datasets (refer to chapter 6.1 5.4.11 Application of correction factors and terms).

6.6 Detailed presentation of test results

Table 41 and Table 42 present an overview of the uncertainties between the reference devices u_{ref} obtained in the field tests.

Table 41: Uncertainty between reference devices u_{ref} for PM_{2.5}

Reference devices	Test site	No. of values	Uncertainty u_{bs}
No.			$\mu\text{g}/\text{m}^3$
1 / 2	Cologne, winter	52	0.54
1 / 2	Bonn, winter	51	0.62
1 / 2	Cologne, summer	46	0.53
1 / 2	Rodenkirchen, summer	45	0.52
1 / 2	All test sites	194	0.55

Table 42: Uncertainty between reference devices u_{ref} for PM₁₀

Reference devices	Test site	No. of values	Uncertainty u_{bs}
Nr.			$\mu\text{g}/\text{m}^3$
1 / 2	Cologne, winter	52	0.54
1 / 2	Bonn, winter	51	0.38
1 / 2	Cologne, summer	47	0.60
1 / 2	Rodenkirchen, summer	33	0.72
1 / 2	All test sites	195	0.58

The uncertainty between the reference devices u_{ref} is $< 2 \mu\text{g}/\text{m}^3$ for all test sites.

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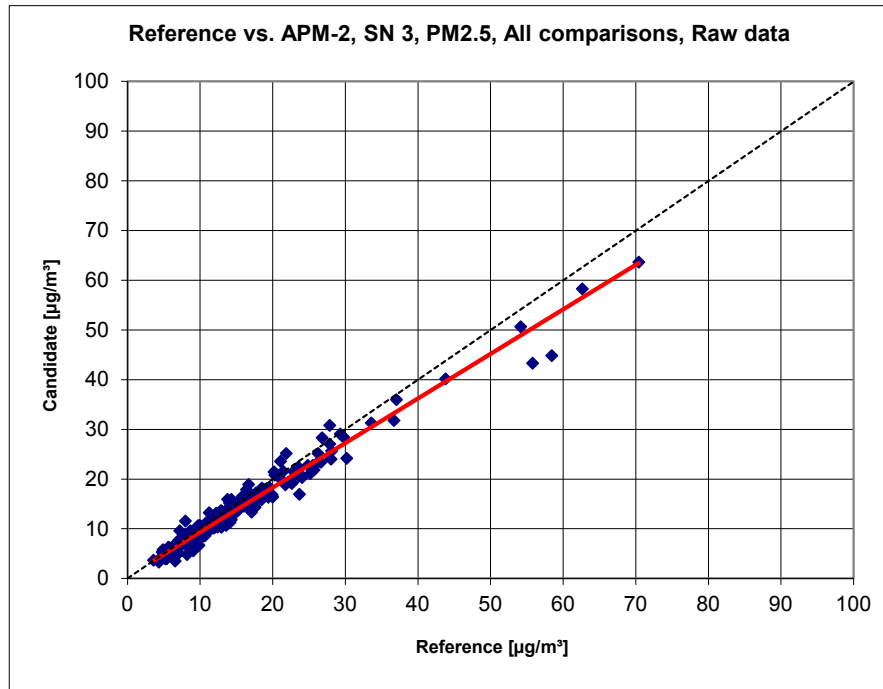


Figure 67: Reference device vs. candidate, SN3, measured component PM_{2.5}, all test sites

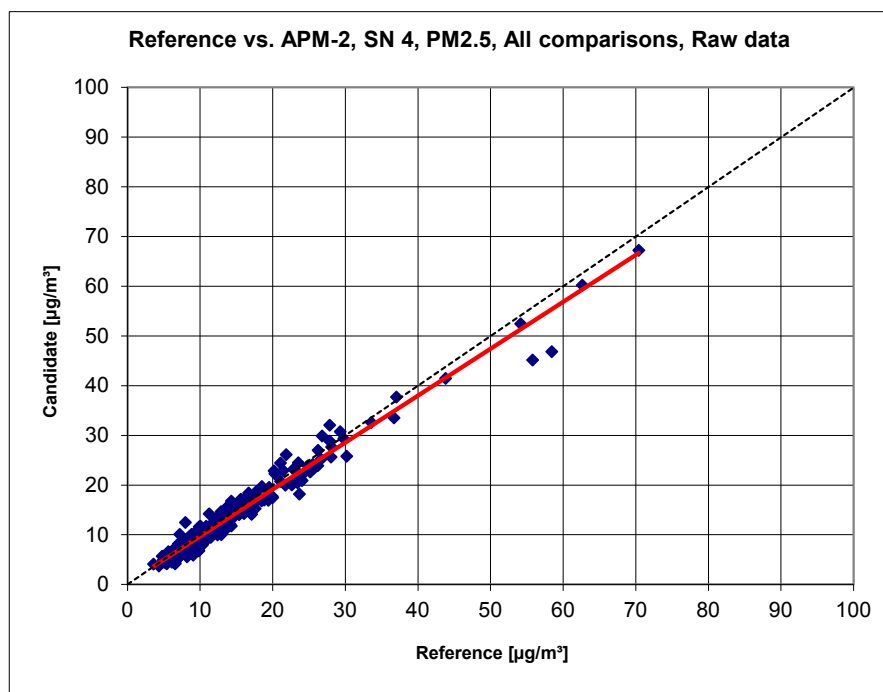


Figure 68: Reference device vs. candidate, SN4, measured component PM_{2.5}, all test sites

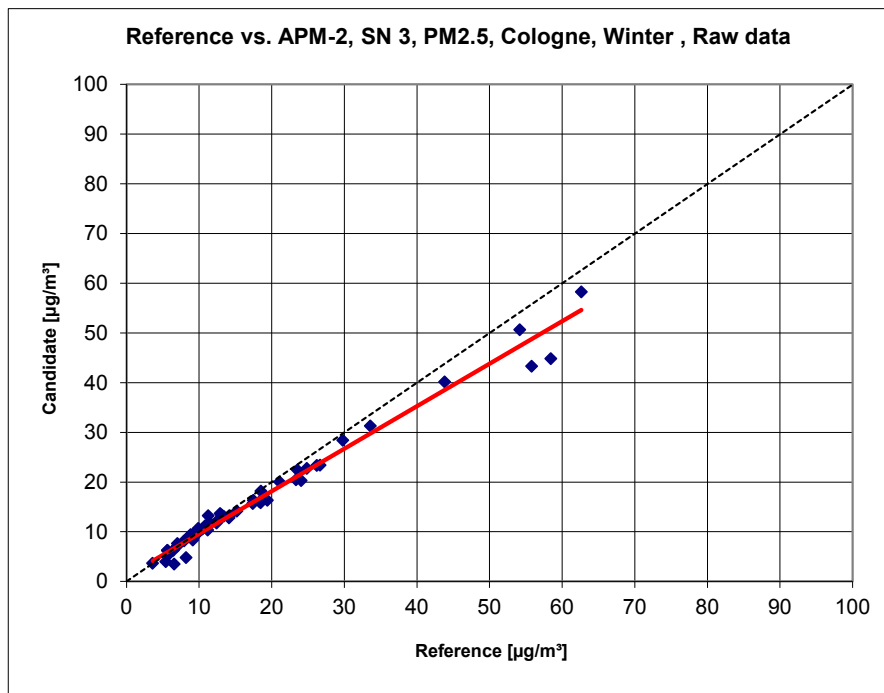


Figure 69: Reference device vs. candidate, SN3, measured component PM_{2.5}, Cologne, winter

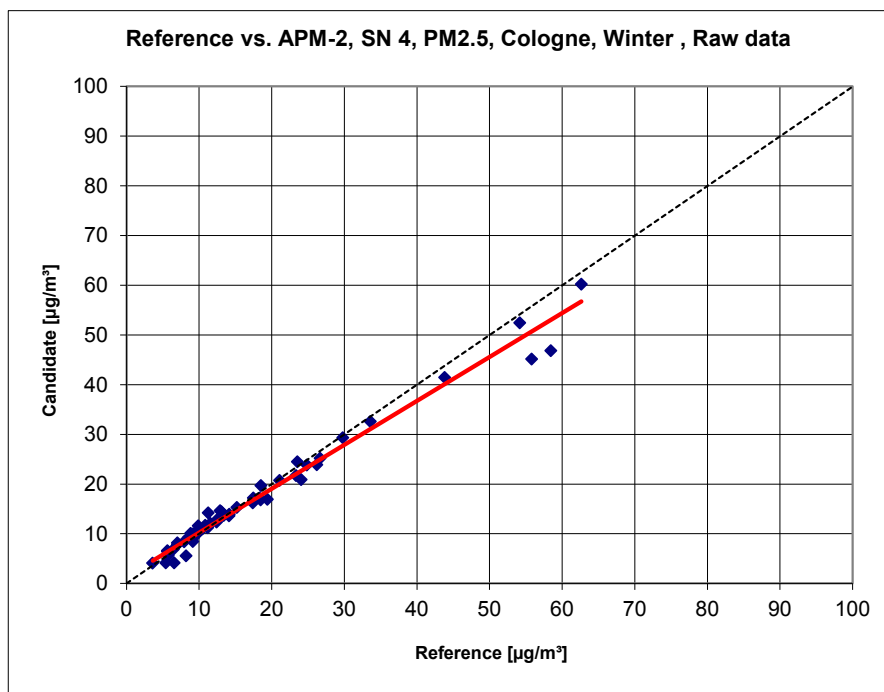


Figure 70: Reference device vs. candidate, SN4, measured component PM_{2.5}, Cologne, winter

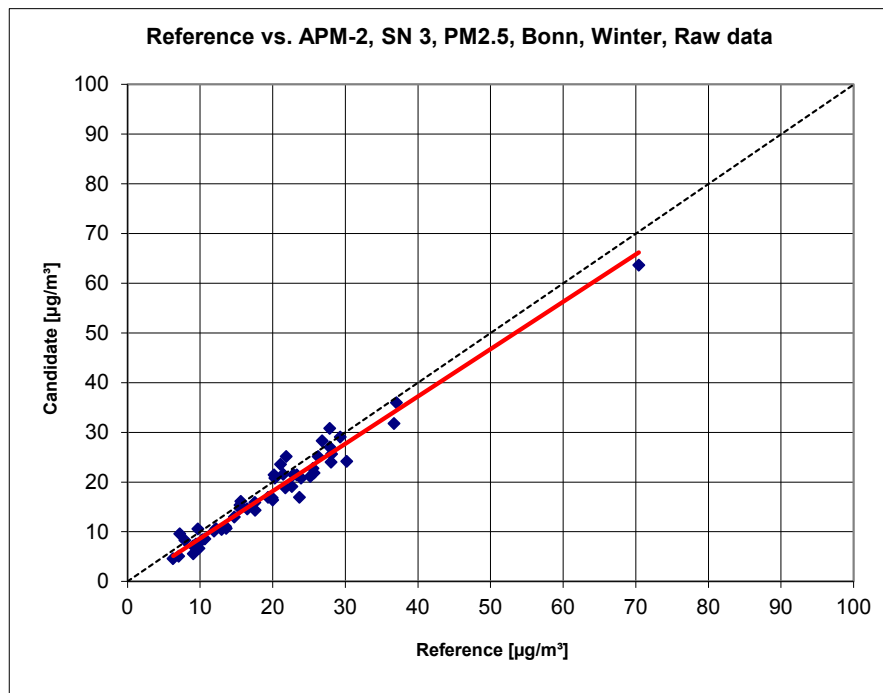


Figure 71: Reference device vs. candidate, SN3, measured component PM_{2.5}, Bonn, winter

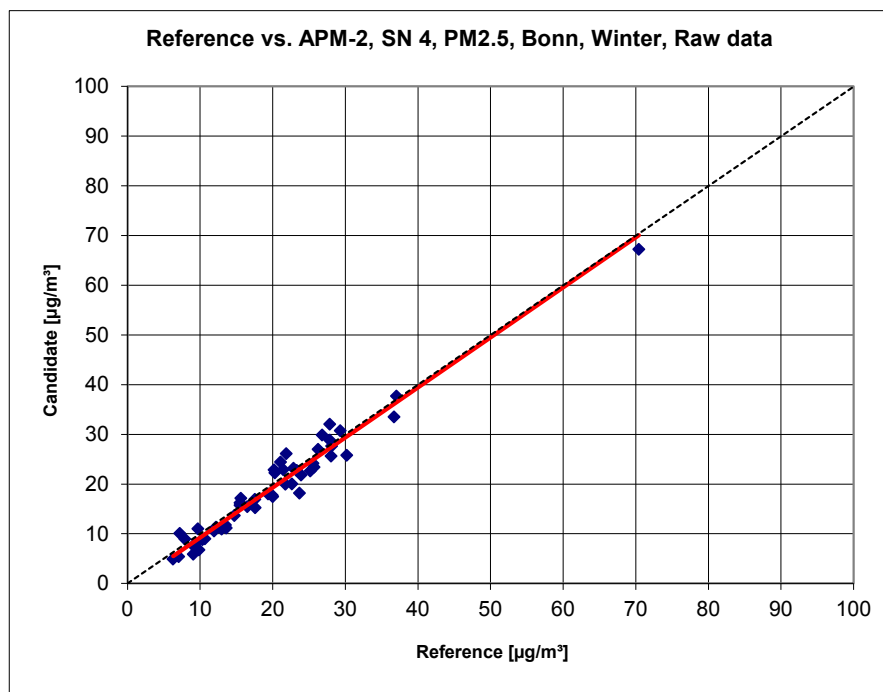


Figure 72: Reference device vs. candidate, SN4, measured component PM_{2.5}, Bonn, winter

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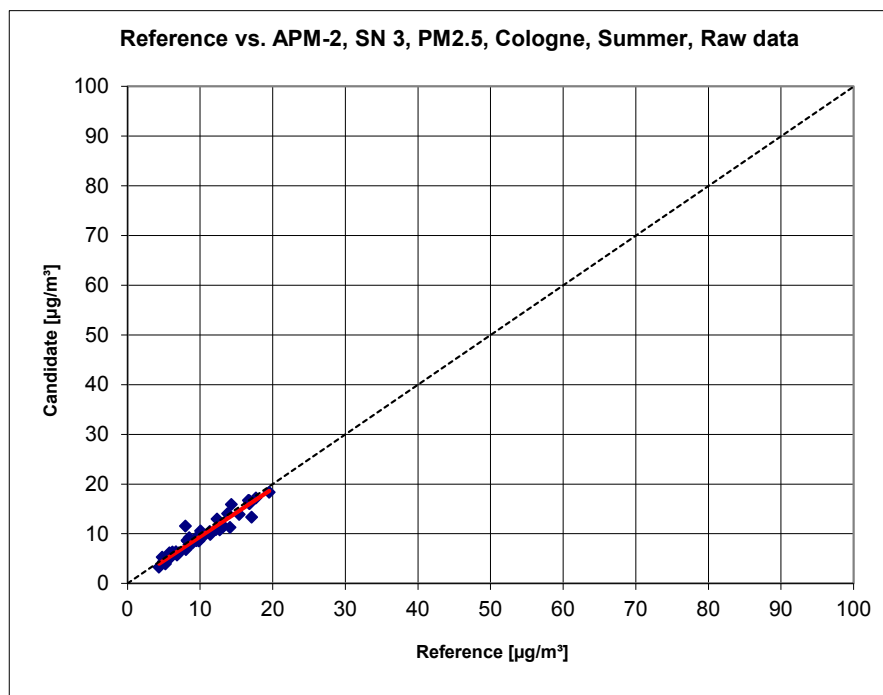


Figure 73: Reference device vs. candidate, SN3, measured component PM_{2.5}, Cologne, summer

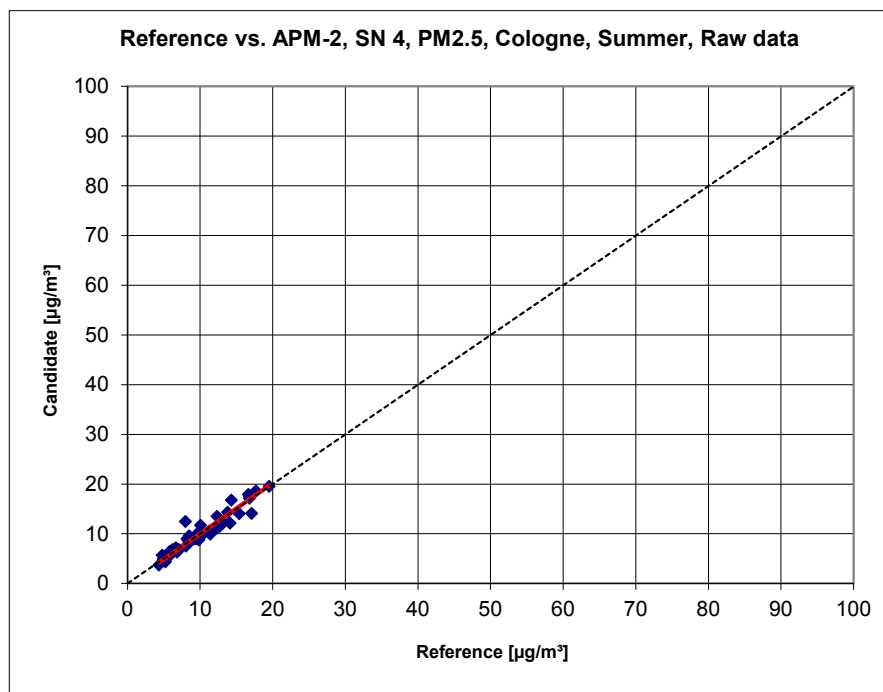


Figure 74: Reference device vs. candidate, SN4, measured component PM_{2.5}, Cologne, summer

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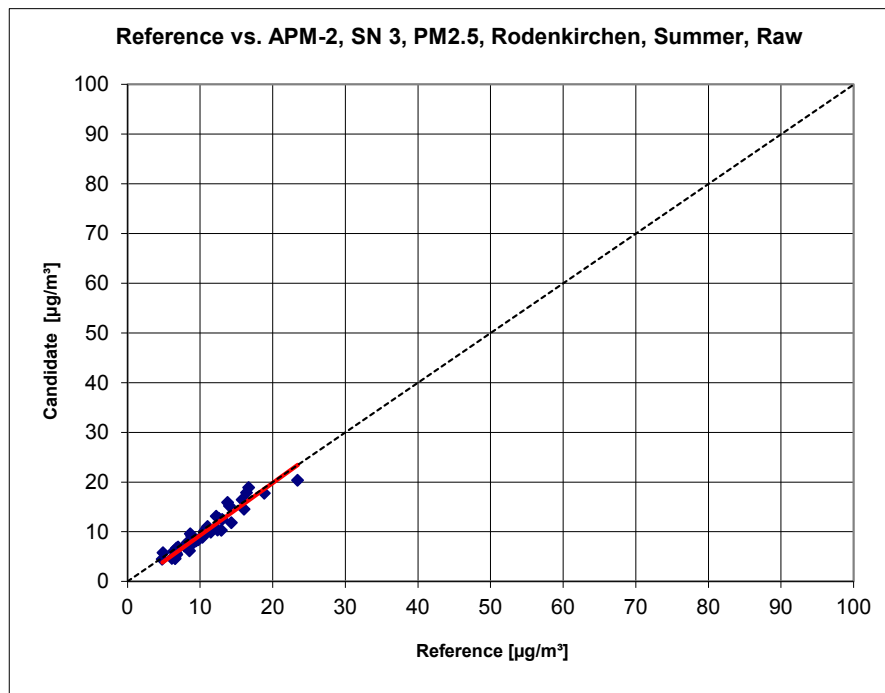


Figure 75: Reference device vs. candidate, SN3, measured component PM_{2.5}, Rodenkirchen, summer

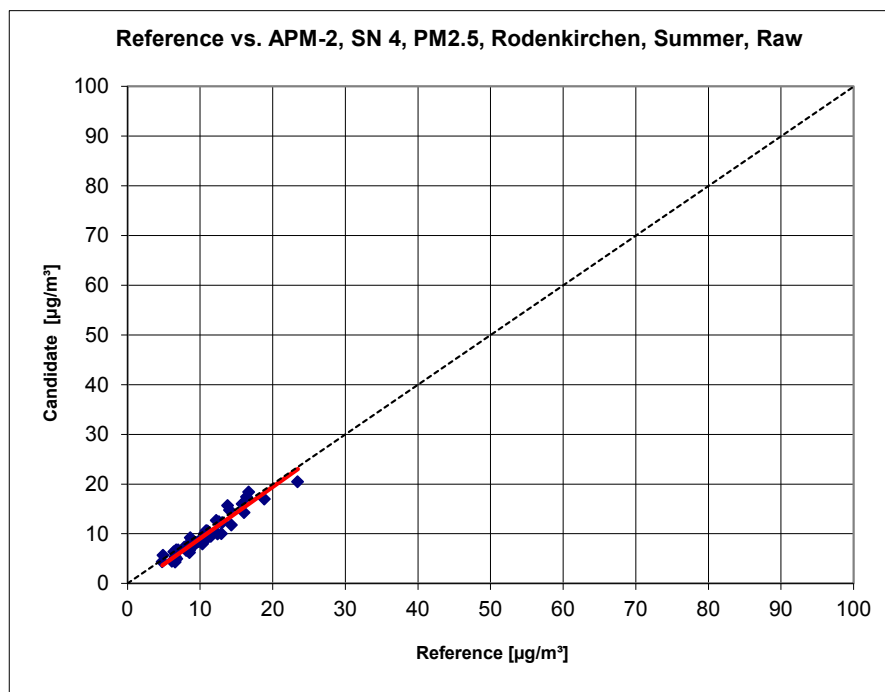


Figure 76: Reference device vs. candidate, SN4, measured component PM_{2.5}, Rodenkirchen, summer

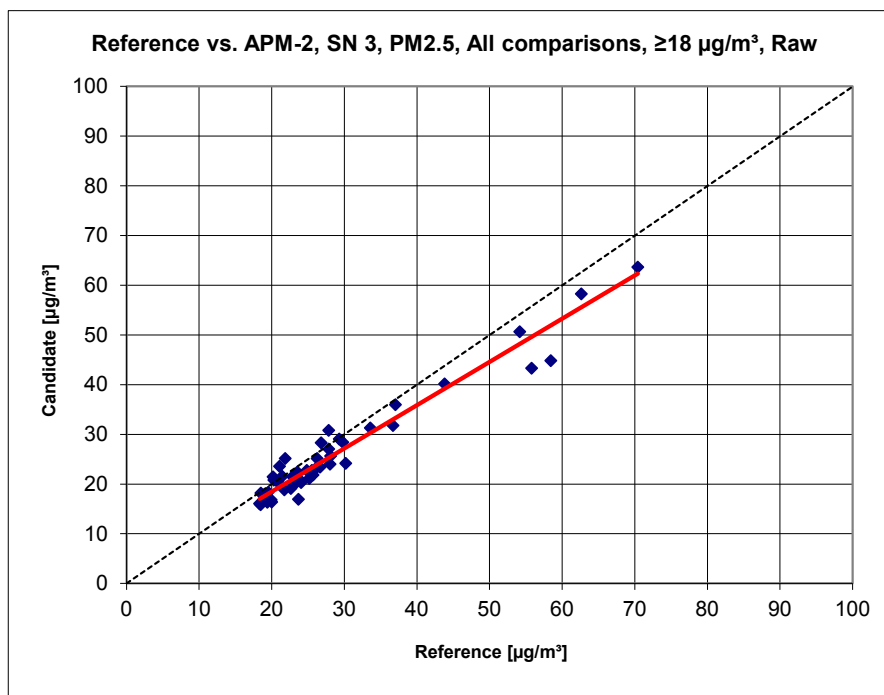


Figure 77: Reference device vs. candidate, SN3, measured component PM_{2.5}, values $\geq 18 \mu\text{g}/\text{m}^3$

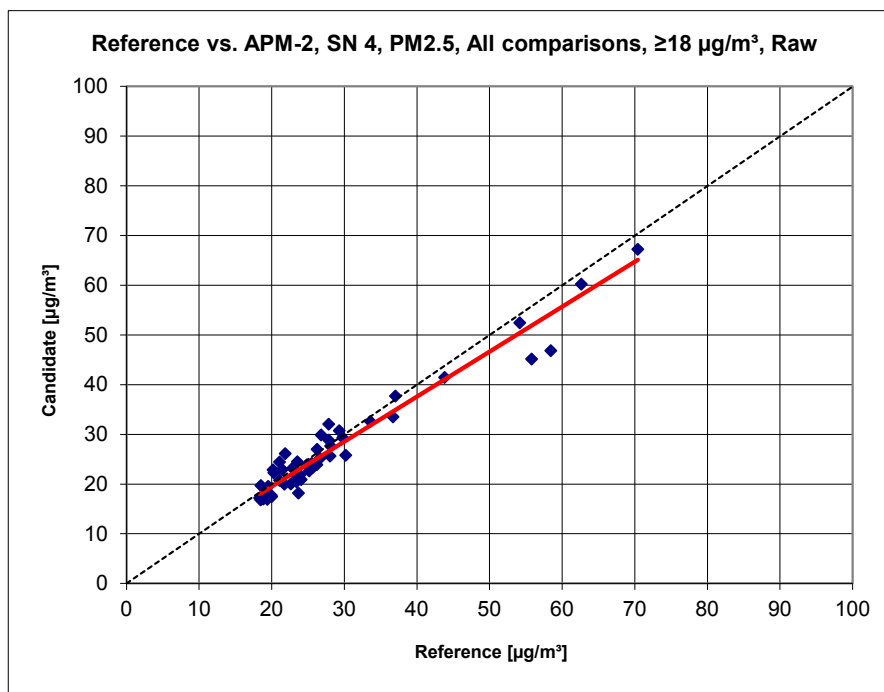


Figure 78: Reference device vs. candidate, SN4, measured component PM_{2.5}, values $\geq 18 \mu\text{g}/\text{m}^3$

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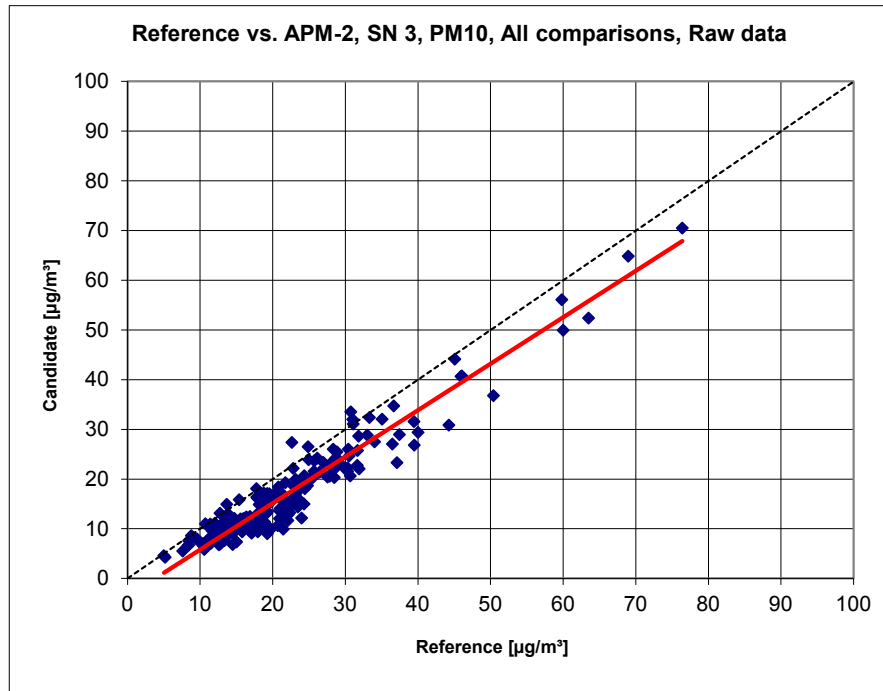


Figure 79: Reference device vs. candidate, SN3, measured component PM₁₀, all test sites

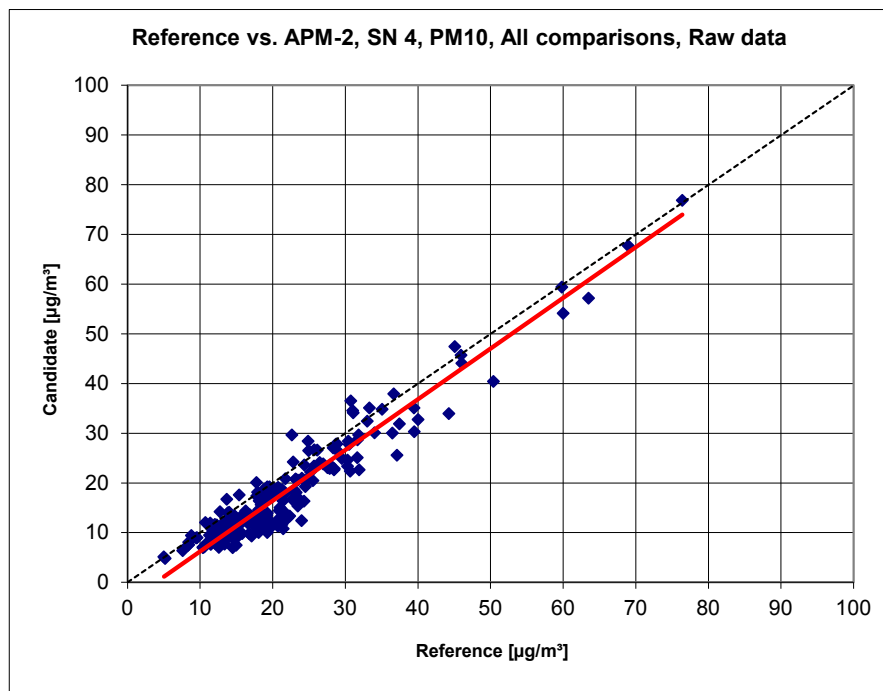


Figure 80: Reference device vs. candidate, SN4, measured component PM₁₀, all test sites

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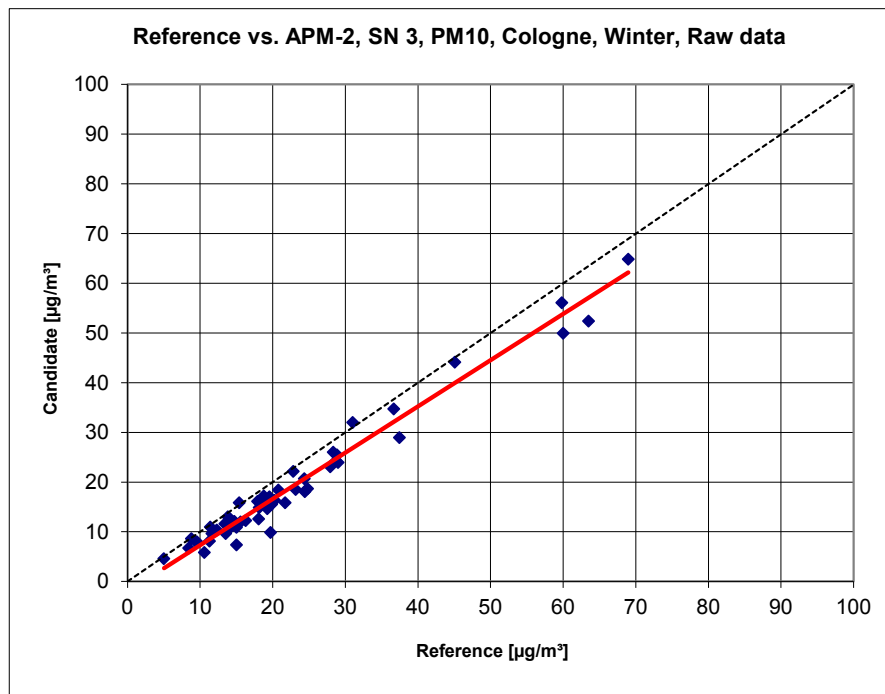


Figure 81: Reference device vs. candidate, SN3, measured component PM₁₀, Cologne, winter

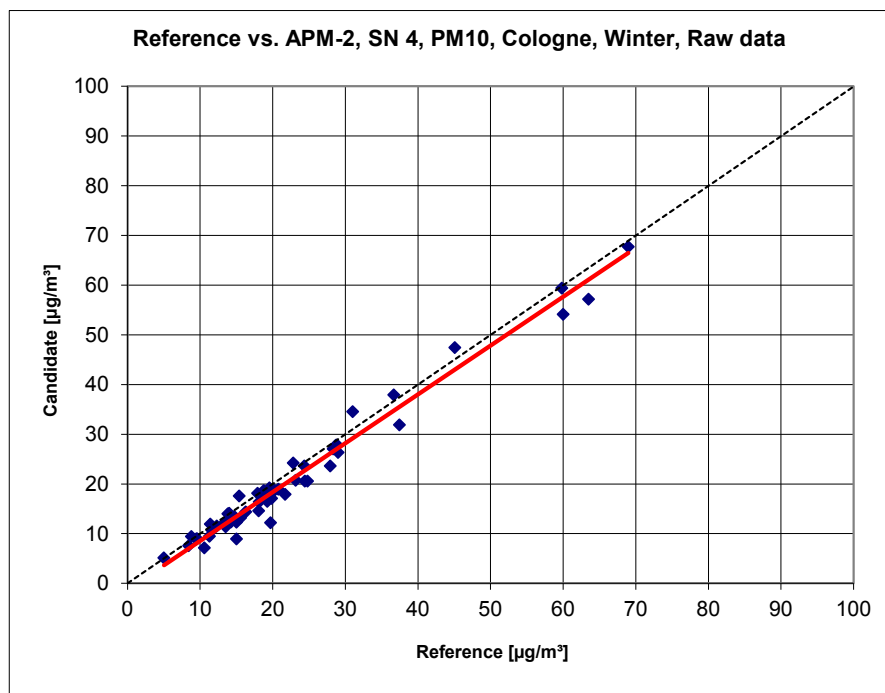


Figure 82: Reference device vs. candidate, SN4, measured component PM₁₀, Cologne, winter

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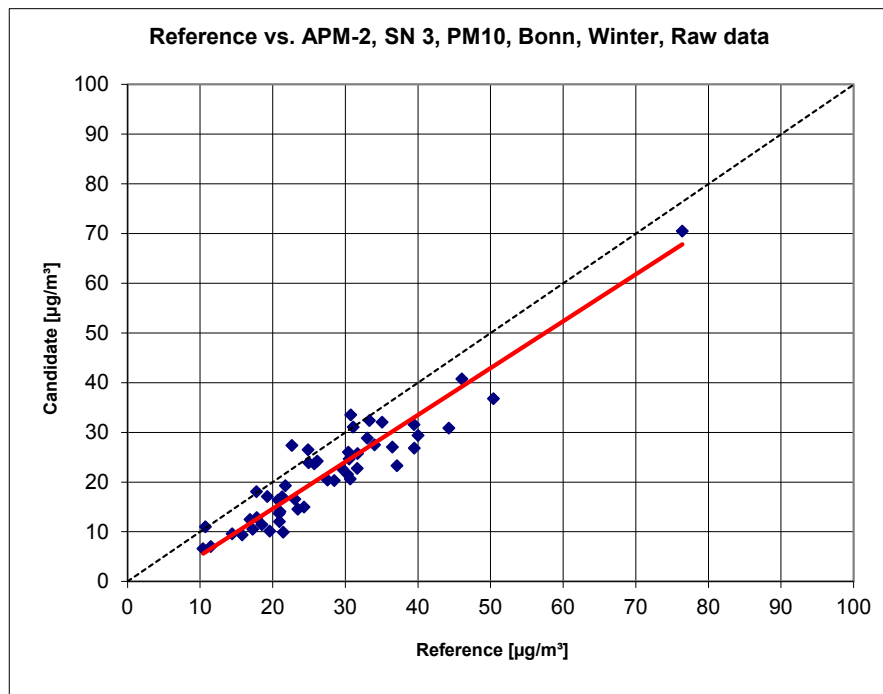


Figure 83: Reference device vs. candidate, SN3, measured component PM₁₀, Bonn, winter

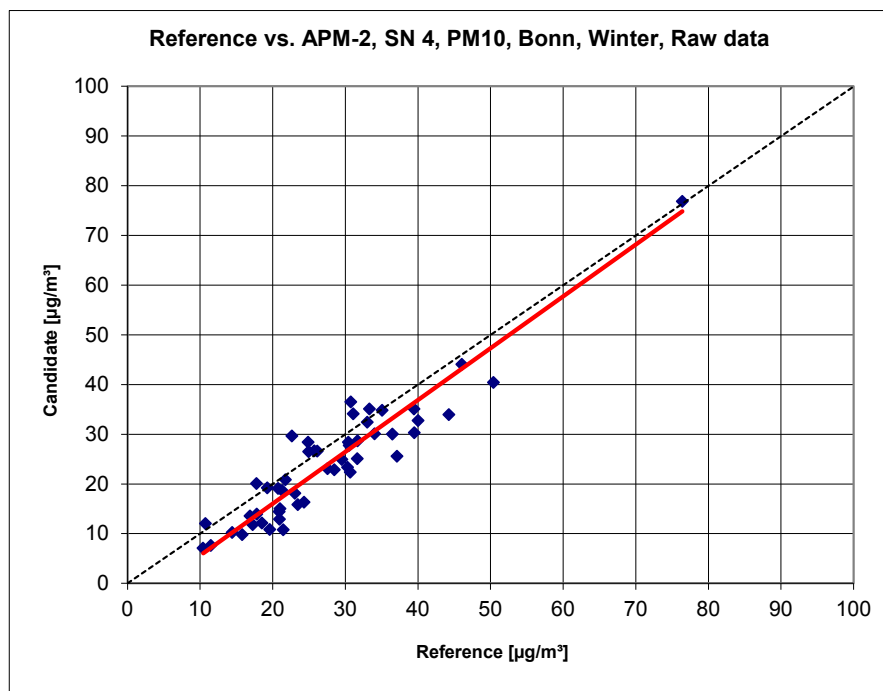


Figure 84: Reference device vs. candidate, SN4, measured component PM₁₀, Bonn, winter

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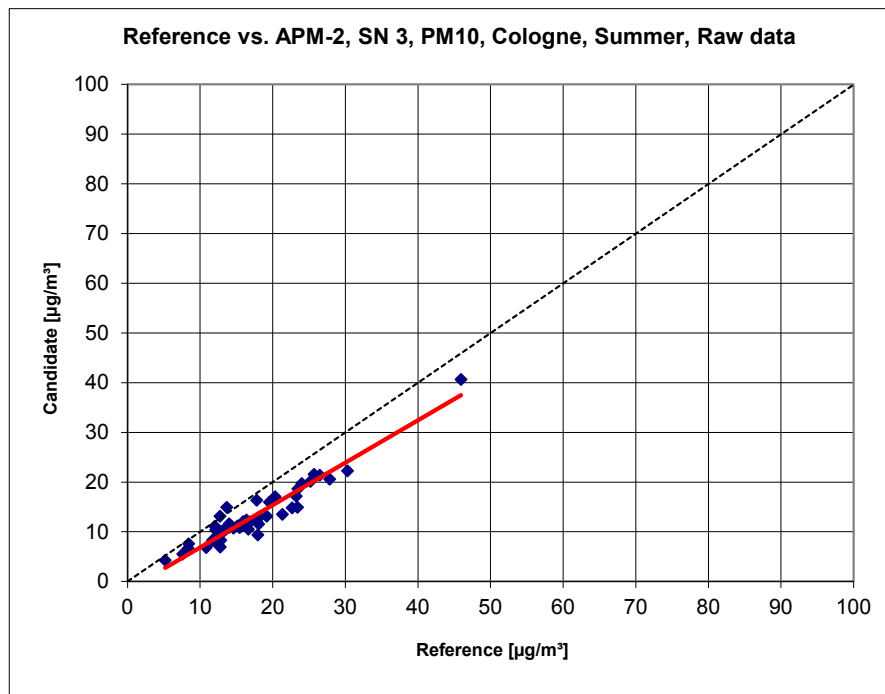


Figure 85: Reference device vs. candidate, SN3, measured component PM₁₀, Cologne, summer

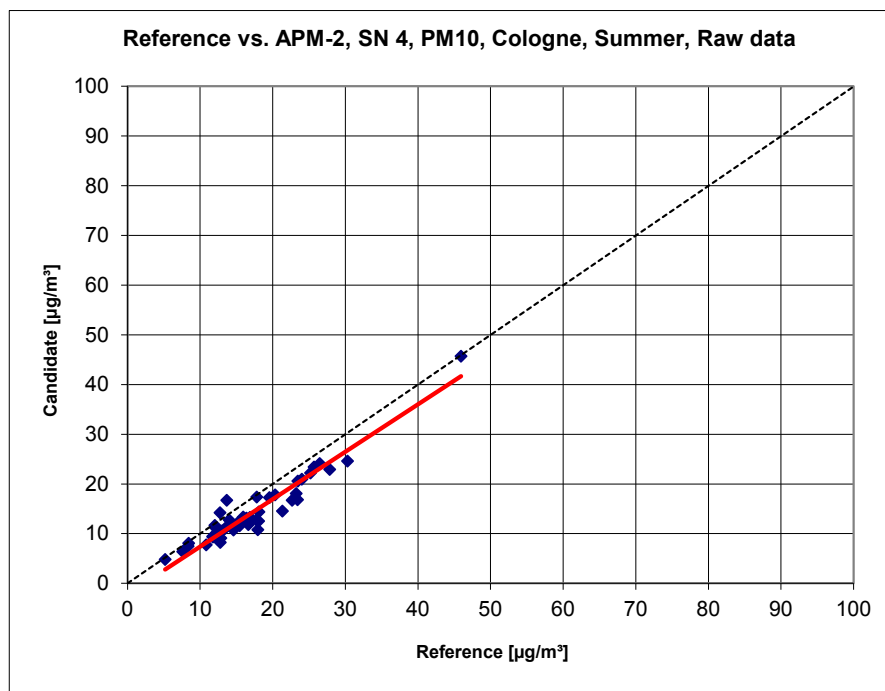


Figure 86: Reference device vs. candidate, SN4, measured component PM₁₀, Cologne, summer

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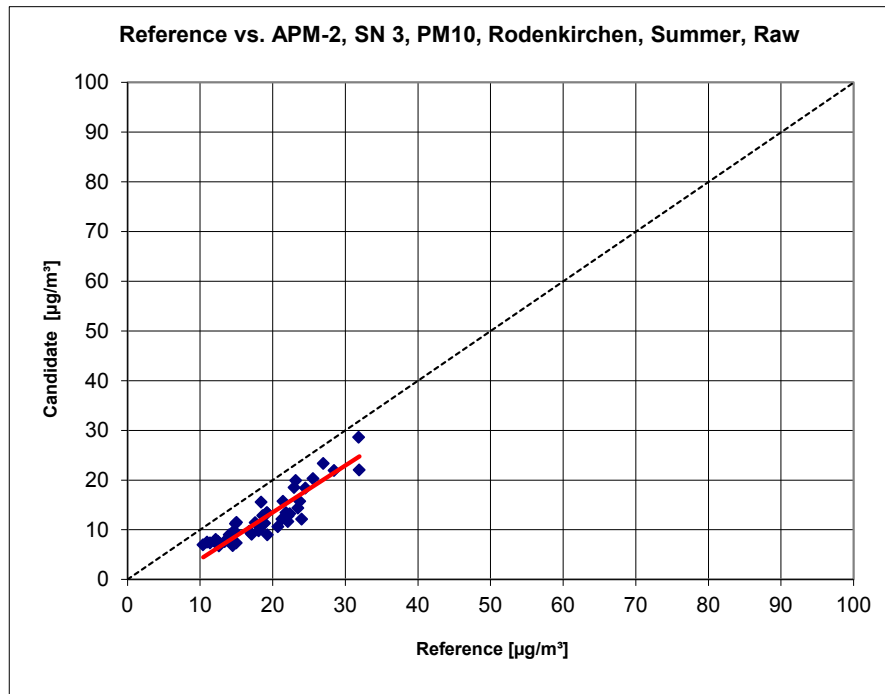


Figure 87: Reference device vs. candidate, SN3, measured component PM₁₀, Rodenkirchen, summer

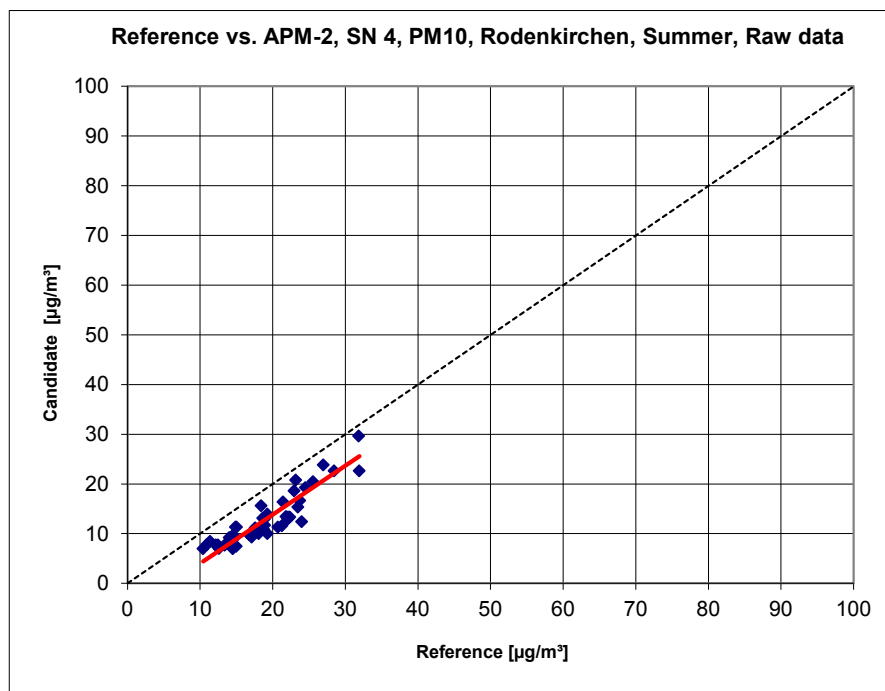


Figure 88: Reference device vs. candidate, SN4, measured component PM₁₀, Rodenkirchen, summer

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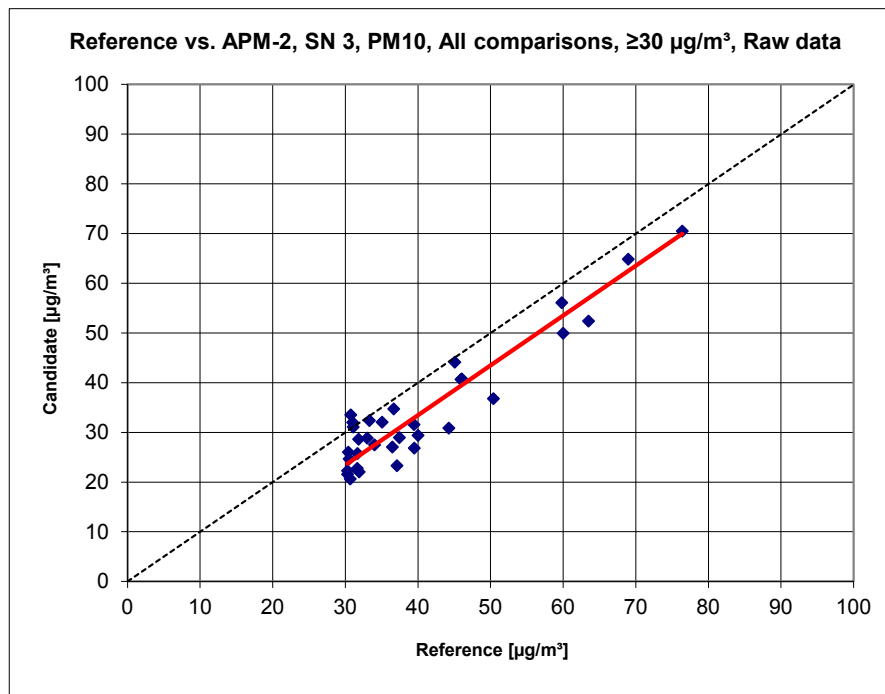


Figure 89: Reference device vs. candidate, SN3, measured component PM₁₀, values $\geq 30 \mu\text{g}/\text{m}^3$

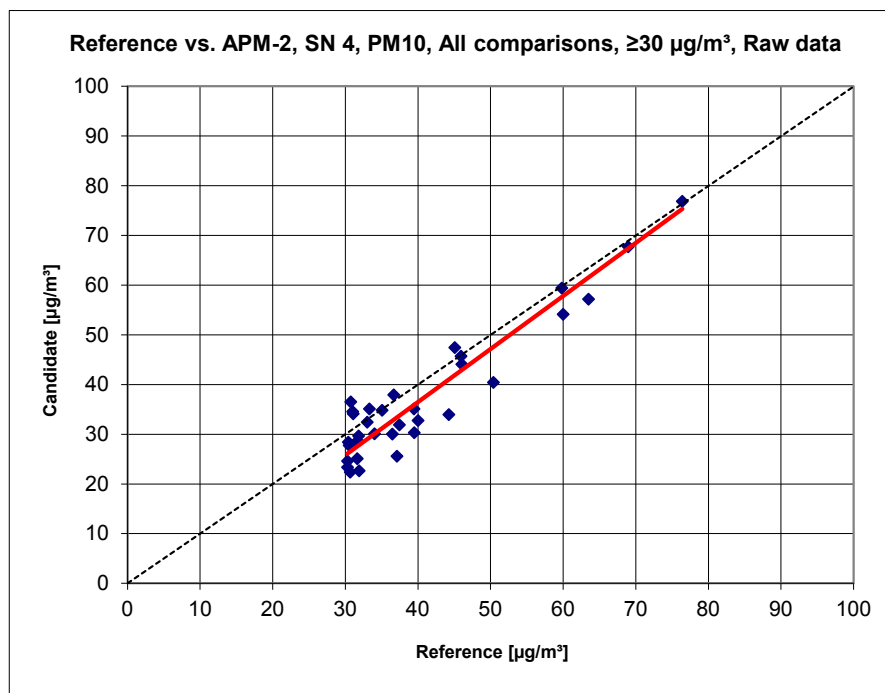


Figure 90: Reference device vs. candidate, SN4, measured component PM₁₀, values $\geq 30 \mu\text{g}/\text{m}^3$

6.1 5.4.11 Application of correction factors and terms

If the maximum expanded uncertainty of the systems under test exceeds the data quality objectives according to Annex B of Standard VDI 4202, Sheet 1 (September 2010) for the test of PM_{2.5} measuring systems, the application of factors and terms is allowed. Values corrected shall meet the requirements of chapter 9.5.3.2ff of the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods".

The tests were also carried out for the component PM₁₀.

6.2 Equipment

No equipment is necessary to test this performance criterion.

6.3 Method

Refer to module 5.4.10.

6.4 Evaluation

If evaluation of the raw data according to module 5.4.10 leads to a case where $W_{CM} > W_{dgo}$, which means that the candidate systems is not regarded equivalent to the reference method, it is permitted to apply a correction factor or term resulting from the regression equation obtained from the full dataset. The corrected values shall satisfy the requirements for all datasets or subsets (refer to module 5.4.10). Moreover, a correction factor may be applied even for $W_{CM} \leq W_{dgo}$ in order to improve the accuracy of the candidate systems.

Three different cases may occur:

- a) Slope b not significantly different from 1: $|b - 1| \leq 2u(b)$,
intercept a significantly different from 0: $|a| > 2u(a)$
- b) Slope b significantly different from 1: $|b - 1| > 2u(b)$,
intercept a not significantly different from 0: $|a| \leq 2u(a)$
- c) Slope b significantly different from 1: $|b - 1| > 2u(b)$
intercept a significantly different from 0: $|a| > 2u(a)$

With respect to a)

The value of the intercept a may be used as a correction term to correct all input values y_i according to the following equation.

$$y_{i,corr} = y_i - a$$

The resulting values of $y_{i,corr}$ may then be used to calculate the following new terms by linear regression:

$$y_{i,corr} = c + dx_i$$

and

$$u_{c-s}^2(y_{i,corr}) = \frac{RSS}{(n-2)} - u^2(x_i) + [c + (d-1)x_i]^2 + u^2(a)$$

with $u(a)$ = uncertainty of the original intercept a , the value of which has been used to obtain $y_{i,corr}$.

Algorithms for the calculation of intercepts as well as slopes and their variances by orthogonal regression are described in detail in annex B of [4]. RSS is determined analogue to the calculation in module 5.4.10.

With respect to b)

The value of the slope b may be used as a term to correct all input values y_i according to the following equation.

$$y_{i,corr} = \frac{y_i}{b}$$

The resulting values of $y_{i,corr}$ may then be used to calculate the following new terms by linear regression:

$$y_{i,corr} = c + dx_i$$

and

$$u_{c-s}^2(y_{i,corr}) = \frac{RSS}{(n-2)} - u^2(x_i) + [c + (d-1)x_i]^2 + x_i^2 u^2(b)$$

with $u(b)$ = uncertainty of the original slope b , the value of which has been used to obtain $y_{i,corr}$.

Algorithms for the calculation of intercepts as well as slopes and their variances by orthogonal regression are described in detail in annex B of [4]. RSS is determined analogue to the calculation in module 5.4.10.

With respect to c)

The values of the slope b and of the intercept a may be used as correction terms to correct all input values y_i according to the following equation.

$$y_{i,corr} = \frac{y_i - a}{b}$$

The resulting values of $y_{i,corr}$ may then be used to calculate the following new terms by linear regression:

$$y_{i,corr} = c + dx_i$$

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and

$$u_{c-s}^2(y_{i,corr}) = \frac{RSS}{(n-2)} - u^2(x_i) + [c + (d-1)x_i]^2 + x_i^2 u^2(b) + u^2(a)$$

with $u(b)$ = uncertainty of the original slope b , the value of which has been used to obtain $y_{i,corr}$ and with $u(a)$ = uncertainty of the original intercept a , the value of which has been used to obtain $y_{i,corr}$.

Algorithms for the calculation of intercepts as well as slopes and their variances by orthogonal regression are described in detail in Annex B of [5]. RSS is determined analogue to the calculation in module 5.4.10.

The values for $u_{c-s,corr}$ are used for the calculation of the combined relative uncertainty of the candidate systems after correction according to the following equation:

$$w_{c,CM,corr}^2(y_i) = \frac{u_{c-s,corr}^2(y_i)}{y_i^2}$$

For the corrected dataset, uncertainty $w_{c,CM,corr}$ is calculated at the daily limit value by taking y_i as the concentration at the limit value.

The expanded relative uncertainty $W_{CM,corr}$ is calculated according to the following equation:

$$W_{CM,corr} = k \cdot w_{CM,corr}$$

In practice: $k=2$ for large number of available experimental results

The highest resulting uncertainty $W_{CM,corr}$ is compared and assessed with the requirements on data quality of ambient air measurements according to EU Standard [8]. Two results are possible:

1. $W_{CM} \leq W_{dgo} \rightarrow$ Candidate method is accepted as equivalent to the standard method.
2. $W_{CM} > W_{dgo} \rightarrow$ Candidate method is not accepted as equivalent to the standard method.

The specified expanded relative uncertainty W_{dgo} for particulate matter is 25 % [8].

6.5 Assessment

Due to application of the correction factors, the candidates meet the requirements on data quality of ambient air quality measurements for all datasets for PM_{2.5} and PM₁₀. For PM_{2.5}, the requirements are met even without application of correction factors. The correction of slope nevertheless leads to an improvement of the expanded measurement uncertainties of the full data comparison.

Performance criterion met? yes

The evaluation of the full dataset for both candidates shows a significant slope for PM_{2.5} and a significant intercept for PM₁₀. For PM₁₀ (SN3) also the slope has been significant.

For PM_{2.5}:

The slope for the full dataset is 0.919 (refer to Table 39).

For PM₁₀:

The slope for the full dataset is 0.977. The intercept for the full dataset -3.758 (refer to Table 40).

For PM_{2.5} a slope correction and for PM₁₀ a slope (due to SN3) and intercept correction for the complete dataset was applied and all datasets were then re-evaluated using the corrected values.

After correction, all datasets fulfil the requirements on data quality and the measurement uncertainties improve significantly at some sites.

The January 2010 version of the Guide requires that the systems are tested annually at a number of sites corresponding to the highest expanded uncertainty found during equivalence testing, if the AMS is operated within a network. The corresponding criterion for determining the number of test sites is divided into 5 % steps (Guide [4], chapter 9.9.2, Table 6). It should be noted that the highest expanded uncertainty determined for PM_{2.5} lies in the range of 10 % to 15 % after correction, while it has been in the range of 15 % to 20 % before correction. For PM₁₀, the highest expanded uncertainty determined lies in the range of 10 % to 15 % after correction, while it has been in the range of 20 % to 25 % before correction.

The network operator or the responsible authority of the member state is responsible for the appropriate realization of the required regular checks in networks mentioned above. However, TÜV Rheinland recommends to use the expanded uncertainty for the full dataset, i.e. for PM_{2.5}: 17.68 % (uncorrected dataset) and 12.36 % (dataset after slope correction), which would require an annual test at 4 measurement sites (uncorrected) or 3 measurement sites (corrected); for PM₁₀: 23.25 % (uncorrected dataset) and 13.55 % (dataset after slope/offset correction), which would require an annual test at 5 measurement sites (uncorrected) or 3 measurement sites (corrected).

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6.6 Detailed presentation of test results

Table 43 and Table 44 present the results of the evaluations of the equivalence test after application of the correction factors for slope and intercept on the complete dataset.

Table 43: *Summary of the results of the equivalence test, SN3 & SN4, measured component PM_{2.5} after correction of slope*

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010				
Candidate	APM-2	SN	SN 3 & SN 4	
Status of measured values	Slope corrected	Limit value	30	µg/m³
		Allowed uncertainty	25	%
All comparisons				
Uncertainty between Reference	0.55			µg/m³
Uncertainty between Candidates	0.71			µg/m³
SN 3 & SN 4				
Number of data pairs	192			
Slope b	1.001			not significant
Uncertainty of b	0.013			
Ordinate intercept a	0.335			not significant
Uncertainty of a	0.235			
Expanded meas. uncertainty W _{CM}	12.36			%
All comparisons, ≥18 µg/m³				
Uncertainty between Reference	0.63			µg/m³
Uncertainty between Candidates	1.13			µg/m³
SN 3 & SN 4				
Number of data pairs	49			
Slope b	0.967			
Uncertainty of b	0.033			
Ordinate intercept a	1.292			
Uncertainty of a	1.019			
Expanded meas. uncertainty W _{CM}	18.46			%
All comparisons, <18 µg/m³				
Uncertainty between Reference	0.53			µg/m³
Uncertainty between Candidates	0.46			µg/m³
SN 3 & SN 4				
Number of data pairs	143			
Slope b	1.137			
Uncertainty of b	0.032			
Ordinate intercept a	-1.073			
Uncertainty of a	0.355			
Expanded meas. uncertainty W _{CM}	22.20			%

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Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010				
Candidate	APM-2	SN	SN 3 & SN 4	
Status of measured values	Slope corrected	Limit value	30	µg/m³
		Allowed uncertainty	25	%
Cologne, Winter				
Uncertainty between Reference	0.54	µg/m³		
Uncertainty between Candidates	0.71	µg/m³		
	SN 3		SN 4	
Number of data pairs	52		52	
Slope b	0.931		0.962	
Uncertainty of b	0.019		0.019	
Ordinate intercept a	1.148		1.495	
Uncertainty of a	0.424		0.435	
Expanded meas. uncertainty W _{CM}	13.83	%	12.92	%
Bonn, Winter				
Uncertainty between Reference	0.62	µg/m³		
Uncertainty between Candidates	0.96	µg/m³		
	SN 3		SN 4	
Number of data pairs	51		51	
Slope b	1.037		1.097	
Uncertainty of b	0.031		0.032	
Ordinate intercept a	-0.948		-0.964	
Uncertainty of a	0.706		0.725	
Expanded meas. uncertainty W _{CM}	15.33	%	20.40	%
Cologne, Summer				
Uncertainty between Reference	0.53	µg/m³		
Uncertainty between Candidates	0.62	µg/m³		
	SN 3		SN 4	
Number of data pairs	46		44	
Slope b	1.054		1.113	
Uncertainty of b	0.044		0.049	
Ordinate intercept a	-0.279		-0.232	
Uncertainty of a	0.493		0.553	
Expanded meas. uncertainty W _{CM}	11.76	%	22.72	%
Rodenkirchen, Summer				
Uncertainty between Reference	0.52	µg/m³		
Uncertainty between Candidates	0.36	µg/m³		
	SN 3		SN 4	
Number of data pairs	45		45	
Slope b	1.150		1.133	
Uncertainty of b	0.050		0.051	
Ordinate intercept a	-1.383		-1.482	
Uncertainty of a	0.565		0.567	
Expanded meas. uncertainty W _{CM}	22.45	%	18.78	%
All comparisons, ≥18 µg/m³				
Uncertainty between Reference	0.63	µg/m³		
Uncertainty between Candidates	1.13	µg/m³		
	SN 3		SN 4	
Number of data pairs	49		49	
Slope b	0.949		0.986	
Uncertainty of b	0.032		0.034	
Ordinate intercept a	1.074		1.497	
Uncertainty of a	1.002		1.05	
Expanded meas. uncertainty W _{CM}	18.25	%	20.15	%
All comparisons, <18 µg/m³				
Uncertainty between Reference	0.53	µg/m³		
Uncertainty between Candidates	0.46	µg/m³		
	SN 3		SN 4	
Number of data pairs	145		143	
Slope b	1.114		1.165	
Uncertainty of b	0.031		0.034	
Ordinate intercept a	-1.015		-1.179	
Uncertainty of a	0.345		0.375	
Expanded meas. uncertainty W _{CM}	18.31	%	26.94	%
All comparisons				
Uncertainty between Reference	0.55	µg/m³		
Uncertainty between Candidates	0.71	µg/m³		
	SN 3		SN 4	
Number of data pairs	194		192	
Slope b	0.976	not significant	1.027	significant
Uncertainty of b	0.013		0.013	
Ordinate intercept a	0.396	not significant	0.269	not significant
Uncertainty of a	0.228		0.245	
Expanded meas. uncertainty W _{CM}	11.97	%	14.57	%

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Table 44: *Summary of the results of the equivalence test, SN3 & SN4, measured component PM₁₀ after correction of slope / intercept*

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010				
Candidate	APM-2	SN	SN 3 & SN 4	
Status of measured values	Slope and Offset corrected	Limit value	50	µg/m³
		Allowed uncertainty	25	%
All comparisons				
Uncertainty between Reference	0.58			µg/m³
Uncertainty between Candidates	1.30			µg/m³
SN 3 & SN 4				
Number of data pairs	193			
Slope b	1.001			nicht signifikant
Uncertainty of b	0.021			
Ordinate intercept a	-0.023			nicht signifikant
Uncertainty of a	0.514			
Expanded measured uncertainty WCM	13.55			%
All comparisons, ≥30 µg/m³				
Uncertainty between Reference	0.72			µg/m³
Uncertainty between Candidates	2.33			µg/m³
SN 3 & SN 4				
Number of data pairs	33			
Slope b	1.061			
Uncertainty of b	0.065			
Ordinate intercept a	-2.800			
Uncertainty of a	2.744			
Expanded measured uncertainty WCM	18.84			%
All comparisons, <30 µg/m³				
Uncertainty between Reference	0.55			µg/m³
Uncertainty between Candidates	0.99			µg/m³
SN 3 & SN 4				
Number of data pairs	160			
Slope b	0.998			
Uncertainty of b	0.041			
Ordinate intercept a	0.114			
Uncertainty of a	0.768			
Expanded measured uncertainty WCM	12.39			%

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Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010				
Candidate	APM-2	SN	SN 3 & SN 4	
Status of measured values	Slope and Offset corrected	Limit value	50	µg/m³
		Allowed uncertainty	25	%
Cologne, Winter				
Uncertainty between Reference	0.54	µg/m³		
Uncertainty between Candidates	1.41	µg/m³		
	SN 3		SN 4	
Number of data pairs	52		52	
Slope b	0.953		1.006	
Uncertainty of b	0.023		0.022	
Ordinate intercept a	1.785		2.520	
Uncertainty of a	0.625		0.596	
Expanded measured uncertainty W _{CM}	10.65	%	15.00	%
Bonn, Winter				
Uncertainty between Reference	0.38	µg/m³		
Uncertainty between Candidates	1.76	µg/m³		
	SN 3		SN 4	
Number of data pairs	51		51	
Slope b	0.967		1.069	
Uncertainty of b	0.051		0.055	
Ordinate intercept a	-0.523		-1.146	
Uncertainty of a	1.511		1.641	
Expanded measured uncertainty W _{CM}	19.25	%	20.76	%
Cologne, Summer				
Uncertainty between Reference	0.60	µg/m³		
Uncertainty between Candidates	1.09	µg/m³		
	SN 3		SN 4	
Number of data pairs	47		45	
Slope b	0.873		0.978	
Uncertainty of b	0.040		0.044	
Ordinate intercept a	2.123		1.622	
Uncertainty of a	0.750		0.828	
Expanded measured uncertainty W _{CM}	18.93	%	9.59	%
Rodenkirchen, Summer				
Uncertainty between Reference	0.76	µg/m³		
Uncertainty between Candidates	0.44	µg/m³		
	SN 3		SN 4	
Number of data pairs	45		45	
Slope b	0.969		1.008	
Uncertainty of b	0.065		0.065	
Ordinate intercept a	-1.719		-2.154	
Uncertainty of a	1.281		1.287	
Expanded measured uncertainty W _{CM}	16.42	%	12.16	%
All comparisons, ≥30 µg/m³				
Uncertainty between Reference	0.72	µg/m³		
Uncertainty between Candidates	2.33	µg/m³		
	SN 3		SN 4	
Number of data pairs	33		33	
Slope b	1.028		1.095	
Uncertainty of b	0.064		0.066	
Ordinate intercept a	-3.024		-2.618	
Uncertainty of a	2.701		2.81	
Expanded measured uncertainty W _{CM}	19.65	%	21.03	%
All comparisons, <30 µg/m³				
Uncertainty between Reference	0.55	µg/m³		
Uncertainty between Candidates	0.99	µg/m³		
	SN 3		SN 4	
Number of data pairs	162		160	
Slope b	0.946		1.053	
Uncertainty of b	0.038		0.044	
Ordinate intercept a	0.486		-0.325	
Uncertainty of a	0.714		0.826	
Expanded measured uncertainty W _{CM}	14.64	%	16.26	%
All comparisons				
Uncertainty between Reference	0.58	µg/m³		
Uncertainty between Candidates	1.30	µg/m³		
	SN 3		SN 4	
Number of data pairs	195		193	
Slope b	0.958	signifikant	1.045	signifikant
Uncertainty of b	0.020		0.022	
Ordinate intercept a	0.190	nicht signifikant	-0.253	nicht signifikant
Uncertainty of a	0.485		0.543	
Expanded measured uncertainty W _{CM}	15.03	%	16.38	%

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6.1 5.5 Requirements on multiple-component measuring systems

Multiple-component measuring systems shall comply with the requirements set for each component, also in the case of simultaneous operation of all measuring channels.

6.2 Equipment

Not applicable.

6.3 Method

The APM-2 is an automated measuring system based on the measurement technology of light scattering. The output of measurements of PM fractions is continuous and alternating every two minutes between the measurement channels PM₁₀ and PM_{2.5}.

The test was carried out in compliance with the requirements on testing the different PM fractions.

6.4 Evaluation

The evaluation of the individual performance criteria was made with regard to the respective measurement components.

6.5 Assessment

Upon assessing the minimum requirements, the measured values for both components were available at the same time (alternating every two minutes between the measurement channels PM₁₀ and PM_{2.5}).

Performance criterion met? yes

6.6 Detailed presentation of test results

No equipment is necessary to test this performance criterion.

7. Investigations for the validation of the instrument software 3.0.1

The instrument manufacturer has developed a new instrument software 3.0.1 for the measuring system APM-2 for winter 2013/2014. This software version contains an optimization of the calculation algorithm by introducing a linearity correction for the measured PM values (an overview on the modifications can be found in Table 5 on page 47).

As this modification has an impact on the formation of measured values, and thus also on the already obtained measured values from the comparison campaigns during type approval test the following measures for qualification of the new software have been agreed upon:

All available measured values of the four past comparison campaigns have been re-calculated manually with the new calculation algorithm and evaluated again. The results of these investigations can be found in chapter 6.1 5.4.10 Calculation of expanded uncertainty between systems under test.

Furthermore an additional comparison campaign at the test site Cologne, parking lot has been conducted with two candidates and the new software version (Version 3.0.1) for qualification. For this the following test program was carried out in detail:

- Performance of a comparison campaign with at minimum 40 valid data pairs reference vs. candidate
- Determination of the in-between uncertainty for the candidates u_{bs} according to the Guide
- Calculation of the expanded uncertainty of the candidates according to the Guide
- Application of the correction factors and terms determined in chapter 6.1 5.4.11 Application of correction factors and terms
- Re-calculation of the equivalence for the 4 data sets of the type approval at hand + additional data set from the validation campaign „Cologne, winter 2014“ according to the approach of chapter „8.2 Suitability test“ of EN/TS 16450 [9]

The additional comparison campaign was carried out at the test site Cologne, parking lot between 13 January 2014 and 09 March 2014. Ambient conditions during that campaign are presented in Table 7. All single values can be found in Annex 5 (PM-measured values) and 6 (ambient conditions).

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There have been 47 valid data pairs both for PM₁₀ and PM_{2.5}.

The evaluation of the comparison measurements according to the Guide [5] lead to the following results:

Table 45: *Results of equivalence test at test site Cologne, winter 2014, SN 3 & SN 4, measured component PM_{2.5}, raw data*

Cologne, Winter 2014			
Uncertainty between Reference	0.49	µg/m ³	
Uncertainty between Candidates	0.61	µg/m ³	
	SN 3		SN 4
Number of data pairs	47		47
Slope b	0.813		0.847
Uncertainty of b	0.019		0.019
Ordinate intercept a	3.122		2.055
Uncertainty of a	0.320		0.313
Expanded meas. uncertainty W _{CM}	18.58	%	18.83 %

Evaluation for PM_{2.5}:

1. The in-between uncertainty of the candidates is 0.61 µg/m³ and thus smaller than the permissible 2.5 µg/m³.
2. The expanded uncertainty for the raw data is smaller than the permissible 25 % for both SN3 and SN4.

Table 46: *Results of equivalence test at test site Cologne, winter 2014, SN 3 & SN 4, measured component PM₁₀, raw data*

Cologne, winter 2014			
Uncertainty between Reference	0.58	µg/m ³	
Uncertainty between Candidates	0.72	µg/m ³	
	SN 3		SN 4
Number of data pairs	47		47
Slope b	0.882		0.927
Uncertainty of b	0.017		0.017
Ordinate intercept a	2.073		1.120
Uncertainty of a	0.380		0.376
Expanded measured uncertainty W _{CM}	16.26	%	11.47 %

Evaluation for PM₁₀:

3. The in-between uncertainty of the candidates is 0.72 µg/m³ and thus smaller than the permissible 2.5 µg/m³.
1. The expanded uncertainty for the raw data is smaller than the permissible 25 % for both SN3 and SN4.

The correction factors / terms, determined during the type approval test in chapter 6.1

5.4.10 Calculation of expanded uncertainty between systems under test are applied to the raw data sets.

Thus the data sets for SN3 and SN4 are corrected with the slope of 0.919 (uncertainty of slope 0.012) for PM_{2,5} with the following results:

Table 47: *Results of equivalence test at test site Cologne, winter 2014, SN 3 & SN 4, measured component PM_{2,5}, slope corrected with 0.919*

Cologne, Winter 2014			
Uncertainty between Reference	0.49	µg/m³	
Uncertainty between Candidates	0.66	µg/m³	
	SN 3		SN 4
Number of data pairs	47		47
Slope b	0.886		0.922
Uncertainty of b	0.021		0.020
Ordinate intercept a	3.385		2.225
Uncertainty of a	0.348		0.341
Expanded meas. uncertainty W _{CM}	9.66	%	9.47
			%

Evaluation:

1. The expanded uncertainty for the data corrected with the slope of 0.919 is smaller than the permissible 25 %.

For PM₁₀ the data sets for SN3 and SN4 are corrected with the slope of 0.977 (uncertainty of slope 0.020) and with the intercept of -3.758 (uncertainty of intercept 0.502) with the following results:

Table 48: *Results of equivalence test at test site Cologne, winter 2014, SN 3 & SN 4, measured component PM₁₀, slope corrected with 0.977, intercept corrected with -3.758*

Cologne, winter 2014			
Uncertainty between Reference	0.58	µg/m³	
Uncertainty between Candidates	0.74	µg/m³	
	SN 3		SN 4
Number of data pairs	47		47
Slope b	0.903		0.949
Uncertainty of b	0.018		0.018
Ordinate intercept a	5.965		4.990
Uncertainty of a	0.389		0.385
Expanded measured uncertainty W _{CM}	8.39	%	12.00
			%

Evaluation:

1. The expanded uncertainty for the data corrected with the slope of 0.977 and the intercept of -3.758 is smaller than the permissible 25 %.

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According to the approach of chapter „8.2 Suitability test“ of EN/TS 16450 [9], the corrected data set for Cologne, winter 2014 was finally added as a fifth data set to the original equivalence test during type approval (refer to Table 43 for PM_{2.5} and Table 44 for PM₁₀) and it was checked, if the criteria of the equivalence test are still fulfilled.

Table 49: *Results of equivalence test „Type approval + Cologne, winter 2014“, SN 3 & SN 4, measured component PM_{2.5}, slope corrected with 0.919*

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010				
Candidate	APM-2	SN	SN 3 & SN 4	
Status of measured values	Slope corrected	Limit value	30	µg/m³
		Allowed uncertainty	25	%
All comparisons				
Uncertainty between Reference	0.54			µg/m³
Uncertainty between Candidates	0.70			µg/m³
	SN 3 & SN 4			
Number of data pairs	239			
Slope b	0.981			not significant
Uncertainty of b	0.012			
Ordinate intercept a	0.872			significant
Uncertainty of a	0.209			
Expanded meas. uncertainty W _{CM}	12.39			%
All comparisons, ≥18 µg/m³				
Uncertainty between Reference	0.64			µg/m³
Uncertainty between Candidates	1.03			µg/m³
	SN 3 & SN 4			
Number of data pairs	61			
Slope b	0.953			
Uncertainty of b	0.030			
Ordinate intercept a	1.663			
Uncertainty of a	0.932			
Expanded meas. uncertainty W _{CM}	18.09			%
All comparisons, <18 µg/m³				
Uncertainty between Reference	0.51			µg/m³
Uncertainty between Candidates	0.52			µg/m³
	SN 3 & SN 4			
Number of data pairs	178			
Slope b	1.069			
Uncertainty of b	0.029			
Ordinate intercept a	-0.010			
Uncertainty of a	0.308			
Expanded meas. uncertainty W _{CM}	16.79			%

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Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010				
Candidate	APM-2	SN	SN 3 & SN 4	
Status of measured values	Slope corrected	Limit value	30	µg/m³
		Allowed uncertainty	25	%
Cologne, winter				
Uncertainty between Reference	0.54			µg/m³
Uncertainty between Candidates	0.71			µg/m³
	SN 3		SN 4	
Number of data pairs	52		52	
Slope b	0.931		0.962	
Uncertainty of b	0.019		0.019	
Ordinate intercept a	1.148		1.495	
Uncertainty of a	0.424		0.435	
Expanded meas. uncertainty W _{CM}	13.83	%	12.92	%
Bonn, winter				
Uncertainty between Reference	0.62			µg/m³
Uncertainty between Candidates	0.96			µg/m³
	SN 3		SN 4	
Number of data pairs	51		51	
Slope b	1.037		1.097	
Uncertainty of b	0.031		0.032	
Ordinate intercept a	-0.948		-0.964	
Uncertainty of a	0.706		0.725	
Expanded meas. uncertainty W _{CM}	15.33	%	20.40	%
Cologne, summer				
Uncertainty between Reference	0.53			µg/m³
Uncertainty between Candidates	0.62			µg/m³
	SN 3		SN 4	
Number of data pairs	46		44	
Slope b	1.054		1.113	
Uncertainty of b	0.044		0.049	
Ordinate intercept a	-0.279		-0.232	
Uncertainty of a	0.493		0.553	
Expanded meas. uncertainty W _{CM}	11.76	%	22.72	%
Rodenkirchen, summer				
Uncertainty between Reference	0.52			µg/m³
Uncertainty between Candidates	0.36			µg/m³
	SN 3		SN 4	
Number of data pairs	45		45	
Slope b	1.150		1.133	
Uncertainty of b	0.050		0.051	
Ordinate intercept a	-1.383		-1.482	
Uncertainty of a	0.565		0.567	
Expanded meas. uncertainty W _{CM}	22.45	%	18.78	%
Cologne, Winter 2014				
Uncertainty between Reference	0.49			µg/m³
Uncertainty between Candidates	0.66			µg/m³
	SN 3		SN 4	
Number of data pairs	47		47	
Slope b	0.886		0.922	
Uncertainty of b	0.021		0.020	
Ordinate intercept a	3.385		2.225	
Uncertainty of a	0.348		0.341	
Expanded meas. uncertainty W _{CM}	9.66	%	9.47	%
All comparisons, ≥18 µg/m³				
Uncertainty between Reference	0.64			µg/m³
Uncertainty between Candidates	1.03			µg/m³
	SN 3		SN 4	
Number of data pairs	61		61	
Slope b	0.935		0.972	
Uncertainty of b	0.030		0.032	
Ordinate intercept a	1.602		1.688	
Uncertainty of a	0.919		0.97	
Expanded meas. uncertainty W _{CM}	17.91	%	19.54	%
All comparisons, <18 µg/m³				
Uncertainty between Reference	0.51			µg/m³
Uncertainty between Candidates	0.52			µg/m³
	SN 3		SN 4	
Number of data pairs	180		178	
Slope b	1.048		1.099	
Uncertainty of b	0.031		0.028	
Ordinate intercept a	0.133		-0.242	
Uncertainty of a	0.329		0.301	
Expanded meas. uncertainty W _{CM}	14.77	%	20.44	%
All comparisons				
Uncertainty between Reference	0.54			µg/m³
Uncertainty between Candidates	0.70			µg/m³
	SN 3		SN 4	
Number of data pairs	241		239	
Slope b	0.956	significant	1.006	not significant
Uncertainty of b	0.012		0.012	
Ordinate intercept a	1.030	significant	0.693	significant
Uncertainty of a	0.212		0.212	
Expanded meas. uncertainty W _{CM}	12.62	%	13.71	%

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Table 50: *Results of equivalence test „Type approval + Cologne, winter 2014“, SN 3 & SN 4, measured component PM₁₀, slope corrected with 0.977, intercept corrected with -3.758*

Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010				
Candidate	APM-2	SN	SN 3 & SN 4	
Status of measured values	Slope and Offset corrected	Limit value	50	µg/m³
		Allowed uncertainty	25	%
All comparisons				
Uncertainty between Reference	0.58			µg/m³
Uncertainty between Candidates	1.22			µg/m³
SN 3 & SN 4				
Number of data pairs	240			
Slope b	0.975			nicht signifikant
Uncertainty of b	0.019			
Ordinate intercept a	1.346			signifikant
Uncertainty of a	0.454			
Expanded measured uncertainty WCM	14.03			%
All comparisons, ≥30 µg/m³				
Uncertainty between Reference	0.68			µg/m³
Uncertainty between Candidates	2.17			µg/m³
SN 3 & SN 4				
Number of data pairs	40			
Slope b	1.052			
Uncertainty of b	0.060			
Ordinate intercept a	-2.041			
Uncertainty of a	2.563			
Expanded measured uncertainty WCM	18.48			%
All comparisons, <30 µg/m³				
Uncertainty between Reference	0.56			µg/m³
Uncertainty between Candidates	0.93			µg/m³
SN 3 & SN 4				
Number of data pairs	200			
Slope b	0.941			
Uncertainty of b	0.036			
Ordinate intercept a	1.975			
Uncertainty of a	0.653			
Expanded measured uncertainty WCM	13.56			%

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Comparison candidate with reference according to Guide "Demonstration of Equivalence Of Ambient Air Monitoring Methods", January 2010				
Candidate	APM-2	SN	SN 3 & SN 4	
Status of measured values	Slope and Offset corrected	Limit value	50	µg/m³
		Allowed uncertainty	25	%
Cologne, winter				
Uncertainty between Reference	0.54	µg/m³		
Uncertainty between Candidates	1.41	µg/m³		
	SN 3		SN 4	
Number of data pairs	52		52	
Slope b	0.953		1.006	
Uncertainty of b	0.023		0.022	
Ordinate intercept a	1.785		2.520	
Uncertainty of a	0.625		0.596	
Expanded measured uncertainty W _{CM}	10.65	%	15.00	%
Bonn, winter				
Uncertainty between Reference	0.38	µg/m³		
Uncertainty between Candidates	1.76	µg/m³		
	SN 3		SN 4	
Number of data pairs	51		51	
Slope b	0.967		1.069	
Uncertainty of b	0.051		0.055	
Ordinate intercept a	-0.523		-1.146	
Uncertainty of a	1.511		1.641	
Expanded measured uncertainty W _{CM}	19.25	%	20.76	%
Cologne, summer				
Uncertainty between Reference	0.60	µg/m³		
Uncertainty between Candidates	1.09	µg/m³		
	SN 3		SN 4	
Number of data pairs	47		45	
Slope b	0.873		0.978	
Uncertainty of b	0.040		0.044	
Ordinate intercept a	2.123		1.622	
Uncertainty of a	0.750		0.828	
Expanded measured uncertainty W _{CM}	18.93	%	9.59	%
Rodenkirchen, summer				
Uncertainty between Reference	0.76	µg/m³		
Uncertainty between Candidates	0.44	µg/m³		
	SN 3		SN 4	
Number of data pairs	45		45	
Slope b	0.969		1.008	
Uncertainty of b	0.065		0.065	
Ordinate intercept a	-1.719		-2.154	
Uncertainty of a	1.281		1.287	
Expanded measured uncertainty W _{CM}	16.42	%	12.16	%
Cologne, winter 2014				
Uncertainty between Reference	0.58	µg/m³		
Uncertainty between Candidates	0.74	µg/m³		
	SN 3		SN 4	
Number of data pairs	47		47	
Slope b	0.903		0.949	
Uncertainty of b	0.018		0.018	
Ordinate intercept a	5.965		4.990	
Uncertainty of a	0.389		0.385	
Expanded measured uncertainty W _{CM}	8.39	%	12.00	%
All comparisons, ≥30 µg/m³				
Uncertainty between Reference	0.68	µg/m³		
Uncertainty between Candidates	2.17	µg/m³		
	SN 3		SN 4	
Number of data pairs	40		40	
Slope b	1.024		1.083	
Uncertainty of b	0.061		0.061	
Ordinate intercept a	-2.267		-1.935	
Uncertainty of a	2.595		2.58	
Expanded measured uncertainty W _{CM}	19.05	%	20.49	%
All comparisons, <30 µg/m³				
Uncertainty between Reference	0.56	µg/m³		
Uncertainty between Candidates	0.93	µg/m³		
	SN 3		SN 4	
Number of data pairs	202		200	
Slope b	0.900		0.987	
Uncertainty of b	0.036		0.037	
Ordinate intercept a	2.238		1.597	
Uncertainty of a	0.652		0.665	
Expanded measured uncertainty W _{CM}	17.00	%	13.72	%
All comparisons				
Uncertainty between Reference	0.58	µg/m³		
Uncertainty between Candidates	1.22	µg/m³		
	SN 3		SN 4	
Number of data pairs	242		240	
Slope b	0.937	signifikant	1.014	nicht signifikant
Uncertainty of b	0.019		0.019	
Ordinate intercept a	1.556	signifikant	1.086	signifikant
Uncertainty of a	0.455		0.460	
Expanded measured uncertainty W _{CM}	15.47	%	15.91	%

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Summary of evaluation:

In order to demonstrate equivalence of the data from the type approval test (comparison campaigns 1-4), manually calculated with the modified calculation algorithm of software 3.0.1. with data obtained with software 3.0.1 under practical conditions, an additional comparison campaign „Cologne, winter 2014“ was carried out with both candidates with software 3.0.1 and the obtained data were equivalence checked. The evaluation leads to the following results:

For PM_{2.5}:

1. The in-between uncertainty of the candidates is 0.61 µg/m³ and thus smaller than the permissible 2.5 µg/m³.
2. The expanded uncertainty for the raw data is smaller than the permissible 25 % for both SN3 and SN4.
3. The expanded uncertainty for the data corrected with the slope of 0.919 (determined in type approval test) is smaller than the permissible 25 % for both SN3 and SN4.
4. The combined evaluation of the four original data sets during type approval (manually re-calculated with the new calculation algorithm and evaluated) with the additional fifth data set of Cologne, winter 2014 (software version 3.0.1 installed) leads also to fulfillment of the equivalence criteria according to the Guide [5].

For PM₁₀:

1. The in-between uncertainty of the candidates is 0.72 µg/m³ and thus smaller than the permissible 2.5 µg/m³.
2. The expanded uncertainty for the raw data is smaller than the permissible 25 % for both SN3 and SN4.
3. The expanded uncertainty for the data corrected with the slope of 0.977 and the intercept of -3.758 (determined in type approval test) is smaller than the permissible 25 % for both SN3 and SN4.
4. The combined evaluation of the four original data sets during type approval (manually re-calculated with the new calculation algorithm and evaluated) with the additional fifth data set of Cologne, winter 2014 (software version 3.0.1 installed) leads also to fulfillment of the equivalence criteria according to the Guide [5].

Thus it has to be noted, that the demonstration of equivalence of the data from the type approval test (comparison campaigns 1-4), manually calculated with the modified calculation algorithm of software 3.0.1. with data obtained with software 3.0.1 under practical conditions could be shown and thus the validation of the current software version 3.0.1 could be finalized in a positive way.

8. Recommendations for practical use

8.1 Works in the maintenance interval (4 weeks)

The following procedures are required to be carried out at regular intervals:

- Check of instrument status
The instrument status may be controlled directly at the instrument or monitored on-line.
- The sampling inlet has to be cleaned in general according to the instructions provided by the manufacturer, at which the local PM conditions have to be considered (during the type approval test approx. every 4 weeks).

As for the rest, the instructions and recommendations provided by the manufacturer shall be followed.

8.2 Further maintenance work

In addition to the regular maintenance work in the maintenance interval, the following procedures are necessary:

- A check of the sensors for ambient temperature and ambient pressure should be carried out every 3 months according to EN TS 16450 [9].
- A check of the flow rate should be carried out every 3 months according to EN TS 16450 [9].
- In the context of the check of the flow rate, a check on tightness should also be carried out every 3 months.
- The virtual impactor has to be cleaned latest every 3 months.
- According to the manufacturer, the internal filters in the device (zero air filter, outlet filter for photometer, bypass filter and pump outlet filter) shall be exchanged latest every 6 months.
- The photometer should be sent to the manufacturer for re-calibration at least once a year.

According to the manufacturer, the photometer has to be completely replaced, if:

- the completely collected PM mass exceeds 50 mg (correspond to approx. 200 days with an average concentration of 50 µg/m³)
- the photometer offset exceeds 2500 mV.

After the annual maintenance of the photometer, the measuring system is to be calibrated at the measurement site with the gravimetric PM₁₀-reference method according to EN 12341 respectively with the gravimetric PM_{2.5}-reference method according to EN 14907. Preferably a seasonal calibration rhythm is to follow.

Report on performance testing of the Air Pollution Monitor 2 (APM-2) measuring system manufactured by Comde-Derenda GmbH for the components suspended particulate matter PM₁₀ and PM_{2.5}, Report no.: 936/21219977/A

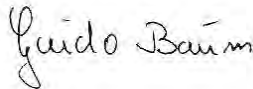
- During the annual basic maintenance the cleaning of the sampling tube has also to be considered.
- The vacuum pump has a life time of approx. 2 years – after reaching the lifetime, the pump must be completely replaced. Failure of the pump is displayed on the system with an error message

Further details are provided in the user manual.

Department of Environmental Protection/Air Pollution Control



Dipl.-Ing. Karsten Pletscher



Dipl.-Ing. Guido Baum

Cologne, 26th March 2014
936/21219977/A

9. Literature

- [1] VDI Standard 4202, Part 1, "Performance criteria for performance tests of automated ambient air measuring systems – Point-related measurement methods for gaseous and particulate air pollutants", June 2002 & September 2010
- [2] VDI Standard 4203, Part 3, "Testing of automated measuring systems – Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants", August 2004 & September 2010
- [3] Standard EN 12341, "Air quality – Determination of the PM₁₀ fraction of suspended particulate matter. Reference method and field test procedure to demonstrate reference equivalence of measurement methods", German version EN 12341: 1998
- [4] Standard EN 14907, "Ambient air quality – Standard gravimetric measurement method for the determination of the PM_{2.5} mass fraction of suspended particulate matter", German version EN 14907: 2005
- [5] Guidance document "Demonstration of Equivalence of Ambient Air Monitoring Methods", English version of January 2010
- [6] Operator's manual APM-2, Version 03/2014
- [7] Operator's manual LVS3, Stand 2000
- [8] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe
- [9] Technical Specification CEN/TS 16450, "Ambient air – Automated measuring systems for the measurement of the concentration of particulate matter (PM₁₀; PM_{2.5})", German version, August 2013
- [10] Report "UK Equivalence Programme for Monitoring of Particulate Matter", Report No.: BV/AQ/AD202209/DH/2396 of 5 June 2006

10. Annex

Appendix 1 Measured and calculated values

- Annex 1: Detection limit
- Annex 2: Temperature dependence of zero point
- Annex 3: Temperature dependence of the sensitivity
- Annex 4: Dependence on supply voltage
- Annex 5: Measured values at the field test sites
- Annex 6: Ambient conditions at the field test sites

Appendix 2 Filter weighing procedure

Appendix 3 Manual

Report on performance testing of the Air Pollution Monitor 2 (APM-2) measuring system manufactured by Comde-Derenda GmbH for the components suspended particulate matter PM10 and PM2.5, Report no.: 936/21219977/A

Annex 1

Detection limit

Page 1 of 1

Manufacturer Comde-Derenda					
Type of instrument APM-2					
Serial-No. SN 3 / SN 4					
Standards ZP Zero point with absolute filter					
No.	Date	Measured values PM _{2,5} [µg/m³]	Measured values PM ₁₀ [µg/m³]	Measured values PM _{2,5} [µg/m³]	Measured values PM ₁₀ [µg/m³]
		SN 3	SN 3	SN 4	SN 4
1	4/18/2012	0.00	0.06	0.00	0.04
2	4/19/2012	0.00	0.00	0.00	0.03
3	4/20/2012	0.00	0.00	0.01	0.03
4	4/21/2012	0.00	0.00	0.00	0.06
5	4/22/2012	0.00	0.00	0.04	0.08
6	4/23/2012	0.00	0.00	0.01	0.01
7	4/24/2012	0.00	0.00	0.04	0.10
8	4/25/2012	0.00	0.00	0.04	0.10
9	4/26/2012	0.00	0.00	0.00	0.03
10	4/27/2012	0.00	0.00	0.00	0.00
11	4/28/2012	0.00	0.00	0.08	0.06
12	4/29/2012	0.00	0.00	0.17	0.13
13	4/30/2012	0.00	0.00	0.00	0.00
14	5/1/2012	0.00	0.00	0.00	0.00
15	5/2/2012	0.00	0.00	0.00	0.00
	Number of values	15	15	15	15
	Mean	0.00	0.00	0.03	0.04
	Standard deviation s _{x0}	0.00	0.01	0.05	0.04
	Detection limit X	<0,01	0.03	0.10	0.09

$$s_{x0} = \sqrt{\left(\frac{1}{n-1}\right) \cdot \sum_{i=1,n} (x_{0i} - \bar{x}_0)^2}$$

Annex 2

Dependence of zero point on ambient temperature

Page 1 of 1

Manufacturer COMDE-DERENDA																																																																																																																																																	
Type APM-2																																																																																																																																																	
Serial-No. SN 3 / SN 4																																																																																																																																																	
<div>Standards</div> <div>ZP</div> <div>Zero filter</div>																																																																																																																																																	
<table border="1"> <thead> <tr> <th colspan="2"></th><th colspan="2">Cycle 1</th><th colspan="2">Cycle 2</th><th colspan="2">Cycle 3</th><th colspan="2"></th><th></th></tr> <tr> <th>SN 3</th><th>No.</th><th>Temperature [°C]</th><th>Measured value [µg/m³]</th><th>Dev. [µg/m³]</th><th>Measured value [µg/m³]</th><th>Dev. [µg/m³]</th><th>Measured value [µg/m³]</th><th>Dev. [µg/m³]</th><th></th><th></th></tr> </thead> <tbody> <tr> <td rowspan="5">ZP</td><td>1</td><td>20</td><td>0.0</td><td>-</td><td>0.0</td><td>-</td><td>0.0</td><td>-</td><td></td><td></td></tr> <tr> <td>2</td><td>-20</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td></td><td></td></tr> <tr> <td>3</td><td>20</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td></td><td></td></tr> <tr> <td>4</td><td>50</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td></td><td></td></tr> <tr> <td>5</td><td>20</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td></td><td></td></tr> <tr> <th>SN 4</th><th>No.</th><th>Temperature [°C]</th><th>Measured value [µg/m³]</th><th>Dev. [µg/m³]</th><th>Measured value [µg/m³]</th><th>Dev. [µg/m³]</th><th>Measured value [µg/m³]</th><th>Dev. [µg/m³]</th><th></th><th></th></tr> <tr> <td rowspan="5">ZP</td><td>1</td><td>20</td><td>0.0</td><td>-</td><td>0.0</td><td>-</td><td>0.0</td><td>-</td><td></td><td></td></tr> <tr> <td>2</td><td>-20</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.1</td><td>0.1</td><td></td><td></td></tr> <tr> <td>3</td><td>20</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td></td><td></td></tr> <tr> <td>4</td><td>50</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td></td><td></td></tr> <tr> <td>5</td><td>20</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td>0.0</td><td></td><td></td></tr> </tbody> </table>													Cycle 1		Cycle 2		Cycle 3					SN 3	No.	Temperature [°C]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]			ZP	1	20	0.0	-	0.0	-	0.0	-			2	-20	0.0	0.0	0.0	0.0	0.0	0.0			3	20	0.0	0.0	0.0	0.0	0.0	0.0			4	50	0.0	0.0	0.0	0.0	0.0	0.0			5	20	0.0	0.0	0.0	0.0	0.0	0.0			SN 4	No.	Temperature [°C]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]			ZP	1	20	0.0	-	0.0	-	0.0	-			2	-20	0.2	0.2	0.2	0.2	0.1	0.1			3	20	0.0	0.0	0.0	0.0	0.0	0.0			4	50	0.0	0.0	0.0	0.0	0.0	0.0			5	20	0.0	0.0	0.0	0.0	0.0	0.0		
		Cycle 1		Cycle 2		Cycle 3																																																																																																																																											
SN 3	No.	Temperature [°C]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]																																																																																																																																									
ZP	1	20	0.0	-	0.0	-	0.0	-																																																																																																																																									
	2	-20	0.0	0.0	0.0	0.0	0.0	0.0																																																																																																																																									
	3	20	0.0	0.0	0.0	0.0	0.0	0.0																																																																																																																																									
	4	50	0.0	0.0	0.0	0.0	0.0	0.0																																																																																																																																									
	5	20	0.0	0.0	0.0	0.0	0.0	0.0																																																																																																																																									
SN 4	No.	Temperature [°C]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]																																																																																																																																									
ZP	1	20	0.0	-	0.0	-	0.0	-																																																																																																																																									
	2	-20	0.2	0.2	0.2	0.2	0.1	0.1																																																																																																																																									
	3	20	0.0	0.0	0.0	0.0	0.0	0.0																																																																																																																																									
	4	50	0.0	0.0	0.0	0.0	0.0	0.0																																																																																																																																									
	5	20	0.0	0.0	0.0	0.0	0.0	0.0																																																																																																																																									

Annex 2

Dependence of zero point on ambient temperature

Page 2 of 2

Manufacturer COMDE-DERENDA										
Type APM-2										
Serial-No. SN 3 / SN 4										
<div>Standards</div> <div>ZP</div> <div>Zero filter</div>										
			Cycle 1		Cycle 2		Cycle 3			
SN 3	No.	Temperature [°C]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]		
ZP	1	20	0.0	-	0.0	-	0.0	-		
	2	-20	0.0	0.0	0.0	0.0	0.0	0.0		
	3	20	0.0	0.0	0.0	0.0	0.0	0.0		
	4	50	0.0	0.0	0.0	0.0	0.0	0.0		
	5	20	0.0	0.0	0.0	0.0	0.0	0.0		
SN 4	No.	Temperature [°C]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]	Measured value [µg/m³]	Dev. [µg/m³]		
ZP	1	20	0.0	-	0.0	-	0.0	-		
	2	-20	0.1	0.1	0.1	0.1	0.1	0.1		
	3	20	0.0	0.0	0.0	0.0	0.0	0.0		
	4	50	0.0	0.0	0.0	0.0	0.0	0.0		
	5	20	0.0	0.0	0.0	0.0	0.0	0.0		

Annex 3

Dependence of measured value on ambient temperature

Page 1 of 1

Manufacturer Comde-Derenda										
Standards ZP Propane test gas										
Type APM-2										
Serial-No. SN 3 / SN 4										
			Cycle 1		Cycle 2		Cycle 3			
SN 3	No.	Temperature [°C]	Measured value mV	Dev. [%]	Measured value mV	Dev. [%]	Measured value mV	Dev. [%]		
RP	1	20	335.4	-	336.0	-	339.3	-		
	2	-20	333.6	-0.5	335.7	-0.1	337.1	-0.6		
	3	20	348.2	3.8	347.6	3.5	342.0	0.8		
	4	50	335.1	-0.1	345.6	2.9	345.6	1.9		
	5	20	330.6	-1.4	330.6	-1.6	332.0	-2.2		
SN 4	No.	Temperature [°C]	Measured value mV	Dev. [%]	Measured value mV	Dev. [%]	Measured value mV	Dev. [%]		
RP	1	20	335.8	-	335.0	-	342.2	-		
	2	-20	333.8	-0.6	333.3	-0.5	331.0	-3.3		
	3	20	333.0	-0.8	332.6	-0.7	339.5	-0.8		
	4	50	334.9	-0.3	342.2	2.1	342.3	0.0		
	5	20	331.8	-1.2	339.0	1.2	338.1	-1.2		

Annex 4

Dependence of measured value on mains voltage

Page 1 of 1

Manufacturer Comde-Derenda										
Type APM-2										
Serial-No. SN 3 / SN 4										
Standards ZP Propane test gas										
			Cycle 1		Cycle 2		Cycle 3			
SN 3	No.	Mains voltage [V]	Measured value	Dev. [%]	Measured value	Dev. [%]	Measured value	Dev. [%]		
RP	1	230	361.5	-	365.0	-	362.9	-		
	2	210	365.2	1.0	365.9	0.3	364.6	0.5		
	3	230	366.6	1.4	368.1	0.8	367.9	1.4		
	4	245	367.8	1.7	367.8	0.8	367.8	1.3		
	5	230	367.9	1.8	367.0	0.5	365.9	0.8		
SN 4	No.	Mains voltage [V]	Measured value	Dev. [%]	Measured value	Dev. [%]	Measured value	Dev. [%]		
RP	1	230	356.1	-	357.3	-	355.1	-		
	2	210	356.8	0.2	356.1	-0.3	353.2	-0.5		
	3	230	353.7	-0.7	353.9	-0.9	350.8	-1.2		
	4	245	351.5	-1.3	351.8	-1.5	351.5	-1.0		
	5	230	353.7	-0.7	351.8	-1.5	349.9	-1.5		

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Annex 5

Measured values from the field test sites, related to ambient conditions

Page 1 of 22

Manufacturer Comde-Derenda Type of instrument APM-2 Serial-No.. SN 3 / SN 4												PM10 and PM2,5 Measured values in µg/m³ (AMB)
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2 PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
1	11/19/2012										Zero point Zero point Zero point Audits	Cologne, winter
2	11/20/2012											
3	11/21/2012											
4	11/22/2012											
5	11/23/2012	15.3	15.1	19.6	19.6	77.8	14.1	15.3	17.0	19.2		
6	11/24/2012						12.5	13.6	15.1	17.2		
7	11/25/2012	5.1	5.8	10.8	10.4	51.1	4.0	4.1	5.8	7.1		
8	11/26/2012	6.1	6.9	11.0	11.6	57.4	6.2	6.8	8.1	9.5		
9	11/27/2012	10.9	11.5	18.5	17.6	62.0	10.3	11.2	12.6	14.6		
10	11/28/2012	23.3	23.5	29.0	29.1	80.5	20.5	21.7	23.9	26.3		
11	11/29/2012	9.0	9.3	14.2	14.4	64.0	9.4	9.9	11.0	12.3		
12	11/30/2012	17.8	19.3	24.5	24.3	76.0	18.1	19.7	20.6	23.6		
13	12/1/2012						13.2	14.1	14.8	16.3		
14	12/2/2012	10.0	11.0	14.8	14.6	71.2	10.5	11.0	12.1	13.4		
15	12/3/2012	8.8	9.0	14.1	14.4	62.2	9.4	10.0	11.3	13.0		
16	12/4/2012	8.3	7.6	11.6	11.6	68.3	8.1	8.4	9.6	10.6		
17	12/5/2012	8.7	8.5	12.1	12.5	69.8	8.9	9.3	10.3	11.5		
18	12/6/2012	9.5	10.3	16.5	16.1	60.7	10.6	11.6	12.2	14.4		
19	12/7/2012	13.0	12.8	15.4	15.4	83.8	13.6	14.6	15.8	17.6		
20	12/8/2012						31.5	33.5	34.5	38.0		
21	12/9/2012	5.5	5.8	10.1	8.9	59.5	6.2	6.4	7.9	8.9		
22	12/10/2012	10.6	11.2	14.5	13.5	77.5	11.2	11.7	12.7	14.1		
23	12/11/2012	17.3	17.7	23.6	22.8	75.4	16.3	17.2	18.5	20.7		
24	12/12/2012	18.2	18.5	24.7	24.2	75.1	16.1	17.2	18.0	20.5		
25	12/13/2012	23.4	23.7	29.3	28.2	82.0	22.4	24.4	24.2	27.8		
26	12/14/2012	7.3	6.7	8.9	8.8	79.5	7.6	8.1	8.6	9.4		
27	12/15/2012						3.8	4.1	5.1	5.9		
28	12/16/2012	5.4	5.9	9.7	9.5	58.9	6.2	6.6	7.9	9.0		
29	12/17/2012	6.8	7.2	13.7	13.4	51.9	7.1	7.8	9.6	11.3		
30	12/18/2012	12.9	13.3	20.1	20.5	64.5	13.4	14.4	16.3	18.7		

Report on performance testing of the Air Pollution Monitor 2 (APM-2) measuring system manufactured by Comde-Derenda GmbH for the components suspended particulate matter PM10 and PM2.5. Report no.: 936/21219977/A

Annex 5

Measured values from the field test sites, related to ambient conditions

Page 2 of 22

Manufacturer	Comde-Derenda										PM10 and PM2,5	
Type of instrument	APM-2										Measured values in µg/m³ (AMB)	
Serial-No..	SN 3 / SN 4											
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
31	12/19/2012	13.4	13.3	18.3	18.0	73.7	13.1	13.6	14.8	16.4		Cologne, winter
32	12/20/2012	11.6	11.6	14.1	13.6	83.8	11.7	12.1	13.0	14.0		
33	12/21/2012	11.7	10.8	18.1	17.8	62.7	13.2	14.2	16.1	18.1		
34	12/22/2012						4.0	4.2	5.3	5.8		
35	12/23/2012						3.5	3.8	4.9	5.7		
36	12/24/2012						6.3	7.1	8.7	10.1		
37	12/25/2012						1.8	2.2	2.8	3.5		
38	12/26/2012						3.2	3.5	5.6	6.5		
39	12/27/2012						8.1	8.8	12.7	14.6		
40	12/28/2012						4.8	5.2	6.1	6.5		
41	12/29/2012						3.6	4.0	4.8	5.3		
42	12/30/2012						3.3	3.6	5.9	6.5		
43	12/31/2012										Power loss	
44	1/1/2013										Power loss	
45	1/2/2013	9.7	9.3	16.1	15.0	60.9	9.6	10.1	11.9	13.1		
46	1/3/2013	11.9	13.1	19.4	18.6	65.6	12.1	12.8	15.9	17.2		
47	1/4/2013	9.5	9.9	13.8	13.0	72.5	9.5	9.9	11.6	12.2		
48	1/5/2013						14.3	15.2	17.4	19.0		
49	1/6/2013	26.7	26.6	37.5	37.4	71.3	23.4	25.2	28.9	31.9		
50	1/7/2013	17.6	19.4	24.6	25.0	74.5	15.8	16.8	18.7	20.5		
51	1/8/2013	13.6	14.7	19.6	20.1	71.4	13.2	13.9	15.5	17.1		
52	1/9/2013	11.6	13.3	18.9	19.7	64.5	11.8	12.3	14.6	16.5		
53	1/10/2013	13.6	14.7	21.9	21.5	65.1	12.8	13.6	15.8	17.9		
54	1/11/2013										Zero point	
55	1/12/2013										Zero point	
56	1/13/2013										Zero point	
57	1/14/2013	24.9	24.8	28.4	29.4	86.0	22.7	23.8	25.5	27.9		
58	1/15/2013	33.4	33.8	36.3	37.1	91.5	31.2	32.6	34.7	37.9		
59	1/16/2013	58.5	58.4	63.7	63.3	92.0	44.8	46.8	52.4	57.1		
60	1/17/2013	55.4	56.2	60.2	59.8	93.0	43.3	45.1	49.9	54.1		

Annex 5

Measured values from the field test sites, related to ambient conditions

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Manufacturer Comde-Derenda												PM10 and PM2,5	
Type of instrument APM-2												Measured values in µg/m³ (AMB)	
Serial-No.. SN 3 / SN 4													
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref.2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site	
61	1/18/2013	17.4	17.5	19.0	18.6	92.7	15.7	16.2	17.2	18.7	Outlier Ref PM10 - not discarded	Cologne, winter	
62	1/19/2013	21.1	21.1	22.6	23.0	92.4	20.0	20.7	22.1	24.2			
63	1/20/2013	29.7	30.0	30.9	31.2	96.2	28.4	29.3	31.9	34.5			
64	1/21/2013	44.9	42.8	45.4	44.8	97.2	40.1	41.4	44.1	47.4			
65	1/22/2013	53.5	54.9			90.5	50.6	52.4	56.0	59.4			
66	1/23/2013	62.1	63.2	69.2	68.8	90.8	58.3	60.2	64.8	67.7			
67	1/24/2013	23.6	24.5	27.8	28.1	86.1	20.3	20.9	23.1	23.6			
68	1/25/2013	19.6	19.3	21.2	20.4	93.3	16.3	16.9	18.4	18.9			
69	1/26/2013	26.6	25.9	28.3	28.4	92.5	23.3	23.9	26.0	27.0			
70	1/27/2013	9.1	9.2	15.0	15.0	61.1	8.3	8.4	10.8	12.3			
71	1/28/2013	5.7	5.9	8.9	7.9	68.6	5.3	5.6	6.7	7.6			
72	1/29/2013	3.4	3.9	5.5	4.5	72.0	3.6	4.1	4.6	5.1			
73	1/30/2013	6.4	6.8	15.2	14.8	43.8	3.5	4.1	7.4	8.9			
74	1/31/2013	8.0	8.5	20.3	19.2	41.6	4.8	5.5	9.8	12.2			
75	2/1/2013	9.2	9.4	11.9	10.9	81.4	8.8	9.2	10.9	11.9			
76	2/2/2013						4.3	4.5	7.8	8.8			
77	2/3/2013						7.9	8.1	9.7	10.4			
78	2/4/2013						5.4	5.9	9.2	10.8			
79	2/5/2013												
80	2/6/2013												
81	2/27/2013										Zero point Zero point Zero point	Bonn, winter	
82	2/28/2013												
83	3/1/2013	24.9	23.0	36.3	36.7	65.6	20.8	21.8	27.0	30.0			
84	3/2/2013						25.1	26.1	31.7	35.4			
85	3/3/2013	22.1	23.2	29.3	29.8	76.6	19.1	20.0	22.7	24.9			
86	3/4/2013	19.6	20.5	28.2	28.7	70.2	16.3	17.4	20.3	22.9			
87	3/5/2013	28.4	27.7	40.2	39.9	70.1	23.9	25.6	29.4	32.7			
88	3/6/2013	25.8	24.5	39.3	39.7	63.8	21.1	22.6	26.8	30.3			
89	3/7/2013	28.0	28.3	39.5	39.5	71.2	25.6	27.6	31.5	35.1			
90	3/8/2013	28.8	27.0	35.4	34.8	79.5	27.0	28.8	32.0	34.8			

Annex 5

Measured values from the field test sites, related to ambient conditions

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Manufacturer		Comde-Derenda									PM10 and PM2,5		
Type of instrument		APM-2									Measured values in µg/m³ (AMB)		
Serial-No..		SN 3 / SN 4											
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2 PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site	
91	3/9/2013						9.9	10.7	12.3	13.5		Bonn, winter	
92	3/10/2013	21.8	22.0	23.1	22.3	96.5	25.1	26.1	27.4	29.6			
93	3/11/2013	27.6	28.1	31.2	30.3	90.6	30.7	32.0	33.5	36.5			
94	3/12/2013	15.6	15.6	17.8	17.7	87.9	16.1	17.1	18.0	20.0			
95	3/13/2013	36.7	36.7	50.8	50.0	72.9	31.8	33.5	36.7	40.4			
96	3/14/2013	19.6	19.2	27.5	27.6	70.3	16.9	18.0	20.4	23.0			
97	3/15/2013	22.0	21.5	31.7	31.7	68.7	18.8	20.0	22.7	25.0			
98	3/16/2013						12.0	12.4	14.6	16.0			
99	3/17/2013	7.0	7.4	11.0	10.5	67.2	9.6	10.1	11.0	12.0			
100	3/18/2013	7.7	8.2	17.4	17.2	45.9	8.3	8.9	10.5	11.8			
101	3/19/2013	9.5	9.9	17.1	16.8	57.5	10.5	11.0	12.4	13.6			
102	3/20/2013	21.3	20.9	25.2	24.5	84.7	23.5	24.4	26.5	28.4			
103	3/21/2013	37.5	36.6	46.3	45.9	80.5	35.9	37.7	40.7	44.0			
104	3/22/2013	21.4	21.6	26.0	26.3	82.2	21.5	22.9	24.2	26.6			
105	3/23/2013						23.1	24.4	25.4	27.9			
106	3/24/2013	15.1	15.9	19.7	18.8	80.6	15.3	16.2	17.1	19.2			
107	3/25/2013	20.1	20.6	26.0	25.6	78.9	20.8	22.2	23.7	26.7			
108	3/26/2013	15.7	15.3	21.1	20.4	74.7	14.7	15.7	16.3	19.1			
109	3/27/2013	26.6	25.9	33.3	32.8	79.5	25.1	27.0	28.8	32.4			
110	3/28/2013						46.0	49.0	51.4	56.5			
111	3/29/2013	71.1	69.8	76.5	76.3	92.2	63.6	67.2	70.5	76.8			
112	3/30/2013												Zero point
113	3/31/2013												Zero point
114	4/1/2013												Zero point
115	4/2/2013	20.2	20.2	24.7	25.2	81.0	21.4	22.8	23.9	26.5			
116	4/3/2013	27.2	26.5	31.4	30.8	86.3	28.2	29.8	31.0	34.1			
117	4/4/2013	29.5	29.1	33.5	33.2	88.0	29.0	30.7	32.4	35.1			
118	4/5/2013	25.8	25.4	30.8	30.0	84.1	22.7	24.1	26.0	28.4			
119	4/6/2013						23.0	24.3	25.9	28.3			
120	4/7/2013	23.0	22.8	30.9	30.2	74.9	21.4	23.2	24.6	27.7			

Annex 5

Measured values from the field test sites, related to ambient conditions

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Manufacturer		Comde-Derenda									PM10 and PM2,5 Measured values in µg/m³ (AMB)	
Type of instrument		APM-2										
Serial-No..		SN 3 / SN 4										
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2 PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
121	4/8/2013	26.3	25.1	31.7	31.7	81.0	21.8	23.4	25.7	28.7	Zero point Zero point Zero point	Bonn, winter
122	4/9/2013	16.5	16.5	21.6	21.0	77.4	14.6	15.5	17.0	18.6		
123	4/10/2013	12.2	12.2	17.9	17.8	68.4	10.6	11.3	12.8	13.9		
124	4/11/2013	9.4	8.8	15.9	15.7	57.4	7.1	7.6	9.4	9.8		
125	4/12/2013	6.2	6.3	10.4	10.4	60.4	4.6	4.9	6.6	7.1		
126	4/13/2013						5.6	5.9	7.8	8.2		
127	4/14/2013	7.2	6.9	11.9	11.1	61.4	5.0	5.4	7.0	7.6		
128	4/15/2013	18.5	16.8	31.2	30.2	57.3	14.3	15.2	20.6	22.3		
129	4/16/2013	12.7	11.2	21.1	20.7	57.2	10.1	10.5	13.6	14.4		
130	4/17/2013	9.9	9.8	19.5	19.7	50.2	6.6	6.8	10.1	10.8		
131	4/18/2013	9.4	8.7	21.4	21.5	42.2	5.6	5.9	9.9	10.8		
132	4/19/2013	10.3	10.3	21.0	20.8	49.4	8.4	8.8	12.0	12.9		
133	4/20/2013						9.6	10.1	12.7	13.8		
134	4/21/2013	24.4	23.0	36.7	37.6	63.8	16.9	18.1	23.3	25.6		
135	4/22/2013	31.0	29.4	44.7	43.9	68.3	24.1	25.7	30.8	33.9		
136	4/23/2013	11.0	10.4	18.2	18.8	57.6	8.5	8.9	11.4	12.1		
137	4/24/2013	14.3	12.7	24.2	24.4	55.6	11.0	11.7	15.0	16.3		
138	4/25/2013	13.8	12.1	23.3	23.6	55.3	10.4	10.9	14.5	15.8		
139	4/26/2013											
140	4/27/2013											
141	4/28/2013											
142	4/29/2013	14.3	12.9	20.6	21.4	64.9	10.7	11.1	14.0	15.0		
143	4/30/2013						13.0	13.8	17.1	18.5		
144	5/1/2013	16.9	18.2	21.4	22.2	80.7	15.9	16.9	19.3	20.8		
145	5/2/2013						16.0	16.9	20.0	21.7		
146	5/3/2013	23.2	23.4	33.7	34.4	68.5	21.4	22.7	27.5	30.1		
147	5/4/2013	20.2	19.7	30.1	30.6	65.7	16.8	17.7	21.5	23.3		
148	5/5/2013	9.6	9.3	14.0	14.8	65.4	7.5	8.0	9.6	10.2		
149	5/6/2013	14.5	15.0	23.3	22.9	63.9	12.9	13.7	16.5	18.1		
150	5/15/2013										Zero point	Cologne, summer

Annex 5

Measured values from the field test sites, related to ambient conditions

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Manufacturer		Comde-Derenda									PM10 and PM2,5 Measured values in µg/m³ (AMB)	
Type of instrument		APM-2										
Serial-No..		SN 3 / SN 4										
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2 PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
151	5/16/2013										Zero point	Cologne, summer
152	5/17/2013	16.7	17.5	19.9	20.8	84.1	13.3	14.1	17.0	17.7		
153	5/18/2013						13.0	13.7	15.2	16.6	SN4 no data recording cause unknown	
154	5/19/2013						15.7	16.6	19.7	21.1		
155	5/20/2013	9.1	10.0	11.6	12.5	79.2	8.6	9.0	11.1	11.7		
156	5/21/2013	5.8	6.3	8.0	8.9	72.0	6.0	6.4	7.6	8.0		
157	5/22/2013	6.5	6.9	13.0	13.1	51.3	6.4	7.1	9.8	10.6		
158	5/23/2013	8.6	9.3	11.6	12.7	73.8	8.1	8.8	10.3	11.1		
159	5/24/2013	8.2	9.3	12.9	13.3	66.8	8.5		10.1			
160	5/25/2013						9.8		12.4			
161	5/26/2013	9.5	10.0	19.5	18.9	50.8	9.1		13.1			
162	5/27/2013	16.8	16.8	24.3	23.8	69.9	16.1	17.6	19.7	20.9		
163	5/28/2013	8.4	8.3	12.5	12.5	66.5	8.5	8.8	10.1	10.7		
164	5/29/2013						7.4	7.7	9.2	9.7		
165	5/30/2013						13.5	14.3	16.4	17.3		
166	5/31/2013						13.5	14.3	16.9	18.5		
167	6/1/2013						11.7	12.4	15.6	17.1		
168	6/2/2013	5.5	6.1	13.0	12.8	45.0	6.1	6.4	8.3	9.1		
169	6/3/2013	8.5	8.5	16.5	16.9	50.9	7.8	8.4	10.5	11.8		
170	6/4/2013	11.8	10.8	21.6	21.2	53.0	10.4	10.6	13.5	14.5		
171	6/5/2013	9.3	9.3	15.9	15.1	60.1	8.7	9.0	10.8	11.6		
172	6/6/2013	11.6	11.3	17.4	18.2	64.1	9.8	9.9	12.0	12.7		
173	6/7/2013	15.3	15.4	23.5	23.0	66.1	13.9	14.0	17.1	18.1		
174	6/8/2013						13.6	14.4	17.4	19.0		
175	6/9/2013	12.6	12.1	20.5	18.7	63.0	12.9	13.5	15.9	17.2		
176	6/10/2013	16.6	16.7	31.1	29.5	55.0	16.7	17.9	22.2	24.6		
177	6/11/2013	14.4	14.3	25.6	24.8	56.8	15.9	16.7	20.1	22.2		
178	6/12/2013	6.6	5.8	15.2	14.1	42.5	6.3	6.8	10.7	10.7		
179	6/13/2013	5.3	4.6	11.2	10.5	45.5	4.4	4.9	6.8	7.7		
180	6/14/2013	6.6	7.1	12.6	12.3	55.0	5.7	6.3	7.5	8.8		

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Measured values from the field test sites, related to ambient conditions

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Manufacturer		Comde-Derenda									PM10 and PM2,5	
Type of instrument		APM-2									Measured values in µg/m³ (AMB)	
Serial-No..		SN 3 / SN 4										
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref.2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
181	6/15/2013	5.7	5.8	12.7	12.9	45.0	4.9	5.5	6.9	8.2	Ref. PM2,5 - stability criteria EN 14907 not met	Cologne, summer
182	6/16/2013	8.1	8.0	18.3	17.6	44.9	6.8	7.5	9.3	10.8		
183	6/17/2013	13.3	13.3	23.3	22.1	58.4	11.5	12.3	14.8	16.7		
184	6/18/2013	16.9	16.7	26.9	26.1	63.5	16.6	17.7	21.4	24.1		
185	6/19/2013			46.8	45.1		33.0	35.7	40.6	45.6		
186	6/20/2013	7.9	8.1	14.2	13.2	58.6	11.5	12.5	14.9	16.7		
187	6/21/2013	4.7	4.9	8.5	8.3	57.5	5.3	5.7	6.6	7.4		
188	6/22/2013	4.0	4.7	5.3	5.1	83.9	3.3	3.7	4.2	4.8		
189	6/23/2013	4.9	5.5	7.7	7.6	68.6	3.9	4.4	5.5	6.4		
190	6/24/2013	9.8	11.1	16.2	15.7	65.3	9.4	9.9	12.0	13.3		
191	6/25/2013	6.8	7.4	11.2	12.3	60.5	6.1	6.8	8.3	9.4	Zero point Zero point	
192	6/26/2013	9.6	10.0	14.4	13.7	69.8	8.9	9.3	10.9	11.6		
193	6/27/2013	9.8	9.8	14.4	13.7	69.7	9.3	10.0	11.6	12.7		
194	6/28/2013	9.7	10.5	12.3	13.2	79.1	10.6	11.7	13.1	14.2		
195	6/29/2013											
196	6/30/2013											
197	7/1/2013	8.9	10.6	17.1	16.7	57.8	9.6	10.1	12.0	13.3		
198	7/2/2013	7.8	8.6	13.9	13.1	60.8	8.7	9.0	10.3	11.0		
199	7/3/2013	5.6	6.9	11.8	11.8	53.2	6.0	6.5	8.3	9.3		
200	7/4/2013	7.8	9.2	15.6	14.8	56.1	9.2	9.6	11.1	12.1		
201	7/5/2013			23.8	23.1		15.0	16.0	18.6	20.6	Outlier Ref. PM2,5	
202	7/6/2013	13.1	14.5	18.1	17.6	77.4	14.0	14.3	16.3	17.3		
203	7/7/2013	11.3	13.1	16.5	16.4	74.2	10.8	11.0	12.3	13.1		
204	7/8/2013	12.3	13.2	18.1	18.2	70.2	10.7	11.5	12.9	14.3		
205	7/9/2013	13.6	14.7	23.5	23.4	60.3	11.2	12.1	14.9	16.8		
206	7/10/2013	10.1	9.6	18.4	17.8	54.4	8.5	8.7	11.5	12.5		
207	7/11/2013	17.5	17.9				17.2	18.6	22.1	24.5	Outlier Ref. PM10	
208	7/12/2013	16.8	16.8	28.9	26.8	60.3	16.0	17.1	20.5	22.9		
209	7/13/2013	19.5	19.5	26.6	24.9	75.9	18.3	19.5	21.5	23.4		
210	7/14/2013						17.0	18.2	20.3	22.6		

Annex 5

Measured values from the field test sites, related to ambient conditions

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Manufacturer		Comde-Derenda									PM10 and PM2.5	
Type of instrument		APM-2									Measured values in µg/m³ (AMB)	
Serial-No..		SN 3 / SN 4										
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2 PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
211	7/30/2013	6.5	6.6	13.7	13.1	49.0	4.9	4.7	7.6	7.7		Rodenkirchen, summer
212	7/31/2013	6.6	6.6	12.0	12.3	54.1	6.0	5.4	8.0	7.7		
213	8/1/2013	8.5	8.6	14.4	15.2	57.7	7.5	6.8	9.6	9.4		
214	8/2/2013	12.0	12.9	20.8	22.9	56.9	10.3	9.9	13.4	13.4		
215	8/3/2013						7.9	7.4	9.9	9.8		
216	8/4/2013	7.1	9.2	14.1	15.0	55.7	7.1	6.6	9.0	8.8		
217	8/5/2013	10.3	10.4	20.2	22.3	48.6	8.8	7.9	12.1	11.6		
218	8/6/2013	9.2	8.7	18.5	19.0	47.6	8.5	7.9	11.2	10.9		
219	8/7/2013	8.8	8.9	15.0	15.1	59.0	9.1	8.7	11.5	11.3		
220	8/8/2013	11.1	10.5	18.8	18.5	58.1	10.4	10.5	12.8	13.1		
221	8/9/2013	10.7	10.6	18.7	19.1	56.3	10.1	10.1	12.9	13.0		
222	8/10/2013						8.1	8.2	10.8	11.1		
223	8/11/2013	4.9	4.9	12.6	12.3	39.5	5.7	5.7	7.7	7.7		
224	8/12/2013	8.0	7.7	18.6	17.6	43.4	7.1	7.3	9.8	10.0		
225	8/13/2013	7.3	6.8	16.5	17.1	41.7	6.9	6.7	9.7	9.8		
226	8/14/2013	9.6	9.0	23.1	24.9	38.8	8.2	7.9	12.1	12.4		
227	8/15/2013	8.5	8.7	19.2	18.6	45.6	8.3	8.2	11.3	11.7		
228	8/16/2013	11.5	11.5	22.2	22.5	51.4	9.9	9.4	13.2	13.3		
229	8/17/2013						6.6	5.7	8.5	7.9		
230	8/18/2013	4.6	5.0	10.7	10.1	46.1	4.5	4.4	6.9	6.9		
231	8/19/2013	6.4	7.1	14.1	14.0	48.3	6.7	6.6	9.0	9.2		
232	8/20/2013	10.7	11.4	19.5	18.9	57.6	11.0	10.6	13.4	13.5		
233	8/21/2013	12.0	12.4	18.8	18.0	66.4	13.1	12.6	15.5	15.6		
234	8/22/2013	15.6	16.0	25.4	25.7	61.9	16.4	16.0	20.3	20.4		
235	8/23/2013	13.6	14.5	22.9	23.0	61.3	15.2	14.8	18.5	18.6		
236	8/24/2013						19.7	19.2	24.9	24.7		
237	8/25/2013	23.4	23.6	32.7	31.0	73.6	20.3	20.4	28.6	29.6		
238	8/26/2013	10.8	10.9	19.2	19.3	56.4	10.6	10.6	13.4	13.9		
239	8/27/2013	12.7	12.5	22.0	20.8	58.8	12.6	12.4	15.7	16.4		
240	8/28/2013	14.1	13.5	22.9	23.5	59.5	15.9	15.7	19.9	20.8		

Annex 5

Measured values from the field test sites, related to ambient conditions

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Manufacturer		Comde-Derenda									PM10 and PM2,5 Measured values in µg/m³ (AMB)	
Type of instrument		APM-2										
Serial-No..		SN 3 / SN 4										
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2 PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
241	8/29/2013	16.3	17.1	26.7	27.2	61.9	18.9	18.4	23.3	23.8		Rodenkirchen, summer
242	8/30/2013	16.6	16.2	27.5	29.5	57.7	17.8	17.4	21.9	22.6		
243	8/31/2013						7.9	8.0	11.5	12.5		
244	9/1/2013	9.7	7.5	18.9	19.6	44.5	6.1	6.2	9.0	10.0		
245	9/2/2013	10.1	9.5	21.2	23.1	44.3	8.4	8.4	11.6	13.0		
246	9/3/2013	13.8	12.3	23.1	24.4	55.0	12.4	12.2	15.7	16.6		
247	9/4/2013	8.9	8.5	14.5	15.3	58.2	9.6	9.2	11.2	11.3		
248	9/5/2013	11.2	10.2	16.2	19.0	60.8	9.5	8.6	11.4	11.1		
249	9/6/2013	19.3	18.5	30.7	33.2	59.1	17.7	16.9	22.0	22.6		
250	9/7/2013	16.6	15.5	24.2	24.9	65.6	14.5	14.3	18.4	19.2		
251	9/8/2013						12.1	13.5	14.6	16.7		
252	9/9/2013	6.7	6.8	11.1	11.7	59.3	5.7	6.7	7.3	8.4		
253	9/10/2013	6.5	6.3	10.9	11.1	58.3	6.1	6.4	7.5	7.8		
254	9/11/2013						10.0	10.0	12.1	12.7		
255	9/12/2013	15.1	13.6	23.0	24.0	60.9	11.8	11.7	14.3	15.3		
256	9/13/2013	8.3	8.4	14.4	14.5	57.6	7.9	7.5	9.4	9.5		
257	9/14/2013						4.1	4.0	5.9	6.3		
258	9/15/2013	6.9	6.8	14.7	15.3	45.5	5.4	5.0	7.3	7.4		
259	9/16/2013	6.6	6.6	14.5	14.6	45.4	4.5	4.3	6.8	7.0		
260	9/17/2013	6.1	6.2	12.4	12.8	48.8	4.6	4.4	6.7	7.0		
261	9/18/2013	13.5	12.4	21.7	22.5	58.4	10.3	10.0	12.8	13.3		
262	9/19/2013	8.3	8.8	16.4	17.8	50.0	6.9	6.6	9.1	9.3		
263	9/20/2013	9.4	9.6	20.7	20.7	45.9	8.2	8.1	10.6	11.3		
264	9/21/2013										Zero point	
265	1/13/2014	12.9	13.6	18.2	18.9	71.5	13.3	12.6	17.2	15.7		Cologne, winter 2014 validation campaign
266	1/14/2014	10.8	11.2	15.5	15.0	72.3	12.5	11.8	15.0	14.1		
267	1/15/2014	5.5	5.7	8.0	8.7	66.9	9.1	7.9	10.4	9.0		
268	1/16/2014	3.1	3.6	6.4	7.1	50.0	6.8	5.5	9.6	7.8		
269	1/17/2014	4.6	5.2	8.9	8.6	56.0	7.3	5.8	9.4	8.2		
270	1/18/2014						12.3	11.5	13.8	12.9		

Annex 5

Measured values from the field test sites, related to ambient conditions

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Manufacturer		Comde-Derenda										PM10 and PM2,5	
Type of instrument		APM-2										Measured values in µg/m³ (AMB)	
Serial-No..		SN 3 / SN 4											
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site	
271	1/19/2014	14.5	14.2	16.8	17.3	84.2	17.3	15.7	19.6	17.7		Cologne, winter 2014 validation campaign	
272	1/20/2014	15.6	15.3	18.9	19.9	79.7	18.4	16.9	22.9	20.4			
273	1/21/2014	24.2	24.6	30.8	31.1	78.7	22.9	22.5	30.1	27.8			
274	1/22/2014	18.4	18.8	23.0	23.5	80.0	19.6	18.8	24.5	22.2			
275	1/23/2014	10.9	11.4	15.2	16.3	70.9	12.1	11.8	15.7	16.3			
276	1/24/2014	18.7	19.3	28.1	28.9	66.6	19.7	19.7	27.5	28.9			
277	1/25/2014						11.2	10.3	15.1	15.1			
278	1/26/2014	4.4	4.4	11.4	12.0	37.8	6.0	5.5	11.5	11.6			
279	1/27/2014	2.9	3.5	6.7	7.1	46.7	5.8	4.3	8.1	7.3			
280	1/28/2014	6.3	6.7	10.9	10.6	60.4	8.3	7.7	10.6	10.6			
281	1/29/2014	16.0	16.6	19.2	19.7	83.8	16.3	16.2	19.3	20.1			
282	1/30/2014	35.7	36.0	41.6	42.3	85.4	36.7	36.9	43.3	45.1			
283	1/31/2014	29.8	29.0	35.0	34.9	84.1	29.4	29.5	35.0	36.5			
284	2/1/2014						8.5	7.0	9.7	8.7			
285	2/2/2014	8.6	7.9	18.1	17.5	46.3	9.6	9.1	17.6	18.0			
286	2/3/2014	18.7	18.0	22.0	21.5	84.5	18.7	18.7	22.2	23.2			
287	2/4/2014						13.8	13.3	17.3	17.3			
288	2/5/2014	4.4	3.4	8.0	8.2	48.6	6.5	5.8	8.9	8.7			
289	2/6/2014	2.9	3.1	9.8	9.1	32.0	5.6	3.8	9.0	8.1			
290	2/7/2014												Zero point Zero point Zero point
291	2/8/2014												
292	2/9/2014												
293	2/10/2014	9.8	8.8	12.9	13.1	71.4	10.9	10.2	13.6	13.6			
294	2/11/2014	4.5	3.8	9.6	8.0	47.6	6.1	5.0	8.3	7.9			
295	2/12/2014	4.5	3.8	8.2	7.9	51.3	5.7	4.3	9.0	8.1			
296	2/13/2014	4.8	4.3	10.3	10.0	44.8	5.7	4.9	9.4	9.2			
297	2/14/2014						4.8	4.5	7.3	7.5			
298	2/15/2014						4.9	3.4	7.5	6.9			
299	2/16/2014	5.2	4.9	8.8	9.2	56.2	6.5	5.7	9.3	9.1			
300	2/17/2014	8.0	7.0	12.7	12.5	59.7	9.1	8.6	12.5	12.3			

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Annex 5

Measured values from the field test sites, related to ambient conditions

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Manufacturer		Comde-Derenda									PM10 and PM2,5	
Type of instrument		APM-2									Measured values in µg/m³ (AMB)	
Serial-No..		SN 3 / SN 4										
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref.2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM2,5 [µg/m³]	SN 4 PM2,5 [µg/m³]	SN 3 PM10 [µg/m³]	SN 4 PM10 [µg/m³]	Remark	Test site
301	2/18/2014	14.5	13.8	19.8	19.6	71.7	14.9	14.0	19.9	19.7	Cologne, winter 2014 validation campaign	
302	2/19/2014	9.6	8.9	13.2	14.2	67.4	11.1	10.6	13.6	13.7		
303	2/20/2014	4.3	4.4	6.6	6.2	67.5	6.7	6.4	8.0	8.1		
304	2/21/2014	4.8	5.0	7.8	7.8	63.2	7.3	6.6	9.7	9.1		
305	2/22/2014	4.2	5.0	4.7	5.4	90.9	7.0	5.8	7.8	6.9		
306	2/23/2014	5.6	6.6	7.1	7.0	87.0	7.7	7.4	8.5	8.6		
307	2/24/2014	9.3	9.3	13.7	12.7	70.6	9.5	8.7	12.6	12.5		
308	2/25/2014	9.0	8.6	12.8	12.1	70.5	9.1	8.9	11.6	12.0		
309	2/26/2014	11.3	11.3	19.4	17.3	61.7	12.0	11.0	17.8	17.4		
310	2/27/2014	7.5	8.2	12.0	10.4	70.3	8.6	8.1	11.9	12.1		
311	2/28/2014	7.7	7.3	10.3	9.9	74.3	8.3	7.7	10.5	10.4		
312	3/1/2014	12.1	12.4	14.7	14.7	83.5	13.2	12.5	15.7	15.8		
313	3/2/2014	16.8	16.9	18.3	19.6	88.6	16.0	16.1	18.7	19.5		
314	3/3/2014	6.8	6.9	9.9	11.8	63.0	9.1	8.5	11.2	11.3		
315	3/4/2014	19.5	17.6	25.6	24.3	74.4	19.3	18.8	24.8	25.2		
316	3/5/2014	30.8	31.2	43.5	43.7	71.0	28.2	27.7	41.4	42.0		
317	3/6/2014	36.5	35.6	44.2	43.5	82.2	29.4	29.5	38.1	39.7		
318	3/7/2014	43.6	44.0	56.7	55.5	78.0	37.1	38.4	48.9	50.9		
319	3/8/2014	42.8	41.4	49.7	50.0	84.4	34.1	33.8	42.7	44.1		
320	3/9/2014	23.2	21.4	28.1	27.2	80.7	19.2	18.7	26.4	26.4		

Annex 5

PM10-Measured values from the field test sites, related to standard conditions [EN 12431]

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Manufacturer		Comde-Derenda		PM10 and PM2,5						
Type of instrument		APM-2		Measured values in µg/m³ (STD)						
Serial-No..		SN 3 / SN 4								
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
1	11/19/2012	-	-						Zero point Zero point Zero point Audits	Cologne, winter
2	11/20/2012	-	-							
3	11/21/2012	-	-							
4	11/22/2012	-	-							
5	11/23/2012	-	-	20.2	20.3	-	17.6	19.9		
6	11/24/2012	-	-			-	15.9	18.1		
7	11/25/2012	-	-	11.2	10.9	-	6.1	7.4		
8	11/26/2012	-	-	11.5	12.2	-	8.5	10.0		
9	11/27/2012	-	-	19.2	18.4	-	13.2	15.3		
10	11/28/2012	-	-	30.0	30.2	-	24.9	27.5		
11	11/29/2012	-	-	14.6	14.8	-	11.3	12.8		
12	11/30/2012	-	-	24.7	24.7	-	21.0	24.1		
13	12/1/2012	-	-			-	15.1	16.7		
14	12/2/2012	-	-	15.1	15.0	-	12.3	13.7		
15	12/3/2012	-	-	14.5	14.8	-	11.6	13.5		
16	12/4/2012	-	-	12.0	12.1	-	10.0	11.1		
17	12/5/2012	-	-	12.3	12.8	-	10.5	11.8		
18	12/6/2012	-	-	16.7	16.3	-	12.4	14.6		
19	12/7/2012	-	-	15.4	15.5	-	15.9	17.7		
20	12/8/2012	-	-			-	34.1	37.6		
21	12/9/2012	-	-	10.4	9.1	-	8.1	9.2		
22	12/10/2012	-	-	14.6	13.7	-	12.9	14.3		
23	12/11/2012	-	-	23.4	22.7	-	18.4	20.7		
24	12/12/2012	-	-	24.6	24.3	-	18.1	20.6		
25	12/13/2012	-	-	29.7	28.7	-	24.7	28.4		
26	12/14/2012	-	-	9.3	9.2	-	9.1	10.0		
27	12/15/2012	-	-			-	5.4	6.2		
28	12/16/2012	-	-	10.1	9.9	-	8.3	9.4		
29	12/17/2012	-	-	14.2	13.9	-	10.0	11.9		
30	12/18/2012	-	-	20.5	21.0	-	16.8	19.2		

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Annex 5

PM10-Measured values from the field test sites, related to standard conditions [EN 12431]

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<p>Manufacturer Comde-Derenda</p> <p>Type of instrument APM-2</p> <p>Serial-No. SN 3 / SN 4</p>										PM10 and PM2,5 Measured values in µg/m³ (STD)
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2 PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
61	1/18/2013	-	-	19.2	18.9	-	17.5	19.0	Outlier Ref PM10 - not discarded	Cologne, winter
62	1/19/2013	-	-	22.9	23.4	-	22.5	24.6		
63	1/20/2013	-	-	31.5	32.0	-	32.8	35.5		
64	1/21/2013	-	-	45.8	45.8	-	45.2	48.7		
65	1/22/2013	-	-	-	-	-	57.2	60.6		
66	1/23/2013	-	-	69.6	69.6	-	65.6	68.7		
67	1/24/2013	-	-	27.7	28.1	-	23.1	23.7		
68	1/25/2013	-	-	-	-	-	18.4	19.0		
69	1/26/2013	-	-	28.5	28.7	-	26.3	27.4		
70	1/27/2013	-	-	15.3	15.4	-	11.1	12.6		
71	1/28/2013	-	-	9.2	8.2	-	6.9	7.9		
72	1/29/2013	-	-	5.8	4.8	-	4.8	5.4		
73	1/30/2013	-	-	15.8	15.6	-	7.7	9.3		
74	1/31/2013	-	-	21.0	20.0	-	10.2	12.7		
75	2/1/2013	-	-	-	-	-	11.4	12.5		
76	2/2/2013	-	-	-	-	-	8.0	9.0		
77	2/3/2013	-	-	-	-	-	10.0	10.7		
78	2/4/2013	-	-	-	-	-	9.6	11.3		
79	2/5/2013	-	-	-	-	-	-	-		
80	2/6/2013	-	-	-	-	-	-	-		
81	2/27/2013	-	-	-	-	-	-	-	Zero point	Bonn, winter
82	2/28/2013	-	-	-	-	-	-	-	Zero point	
83	3/1/2013	-	-	36.6	37.1	-	27.3	30.4	Zero point	
84	3/2/2013	-	-	-	-	-	32.0	35.8		
85	3/3/2013	-	-	29.5	30.2	-	23.0	25.2		
86	3/4/2013	-	-	28.9	29.7	-	20.9	23.6		
87	3/5/2013	-	-	41.8	41.8	-	30.8	34.3		
88	3/6/2013	-	-	41.5	42.3	-	28.6	32.4		
89	3/7/2013	-	-	41.9	42.3	-	33.9	37.7		
90	3/8/2013	-	-	37.8	37.4	-	34.6	37.6		

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PM10-Measured values from the field test sites, related to standard conditions [EN 12431]

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Manufacturer		Comde-Derenda		PM10 and PM2,5							
Type of instrument		APM-2		Measured values in µg/m³ (STD)							
Serial-No..		SN 3 / SN 4									
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2 PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site	
91	3/9/2013	-	-			-	13.1	14.4		Bonn, winter	
92	3/10/2013	-	-	23.6	22.9	-	28.2	30.5			
93	3/11/2013	-	-	31.5	30.8	-	34.0	37.1			
94	3/12/2013	-	-	17.9	17.9	-	18.2	20.2			
95	3/13/2013	-	-	51.3	50.9	-	37.2	41.0			
96	3/14/2013	-	-	27.5	27.9	-	20.5	23.2			
97	3/15/2013	-	-	32.0	32.3	-	23.1	25.5			
98	3/16/2013	-	-			-	15.1	16.6			
99	3/17/2013	-	-	11.4	11.0	-	11.5	12.6			
100	3/18/2013	-	-	18.2	18.1	-	11.1	12.5			
101	3/19/2013	-	-	17.7	17.5	-	13.0	14.2			
102	3/20/2013	-	-	25.8	25.2	-	27.2	29.1			
103	3/21/2013	-	-	46.4	46.3	-	41.0	44.4			
104	3/22/2013	-	-	26.4	26.8	-	24.7	27.1			
105	3/23/2013	-	-			-	25.7	28.3			
106	3/24/2013	-	-	19.9	19.1	-	17.3	19.5			
107	3/25/2013	-	-	26.2	25.9	-	24.0	27.1			
108	3/26/2013	-	-	21.4	20.8	-	16.6	19.5			
109	3/27/2013	-	-	33.9	33.6	-	29.5	33.2			
110	3/28/2013	-	-			-	52.9	58.1			
111	3/29/2013	-	-	78.1	77.4	-	71.8	78.4			
112	3/30/2013	-	-			-					Zero point Zero point Zero point
113	3/31/2013	-	-			-					
114	4/1/2013	-	-			-					
115	4/2/2013	-	-	25.2	25.8	-	24.5	27.2			
116	4/3/2013	-	-	31.9	31.5	-	31.7	34.8			
117	4/4/2013	-	-	34.3	34.2	-	33.4	36.2			
118	4/5/2013	-	-	31.5	30.8	-	26.7	29.1			
119	4/6/2013	-	-			-	26.3	28.8			
120	4/7/2013	-	-	31.7	31.2	-	25.4	28.6			

Annex 5

PM10-Measured values from the field test sites, related to standard conditions [EN 12431]

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Manufacturer		Comde-Derenda								
Type of instrument		APM-2								
Serial-No..		SN 3 / SN 4								
PM10 and PM2,5 Measured values in µg/m³ (STD)										
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2 PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
121	4/8/2013	-	-	32.9	33.1	-	26.9	30.0	Zero point Zero point Zero point	Bonn, winter
122	4/9/2013	-	-	22.6	22.2	-	18.0	19.7		
123	4/10/2013	-	-	18.7	18.8	-	13.6	14.7		
124	4/11/2013	-	-	16.9	16.9	-	10.1	10.6		
125	4/12/2013	-	-	11.0	11.1	-	7.0	7.5		
126	4/13/2013	-	-			-	8.2	8.7		
127	4/14/2013	-	-	12.6	11.9	-	7.5	8.2		
128	4/15/2013	-	-	33.0	32.3	-	22.1	23.9		
129	4/16/2013	-	-	22.4	22.2	-	14.6	15.5		
130	4/17/2013	-	-	20.9	21.2	-	10.9	11.7		
131	4/18/2013	-	-	22.6	22.9	-	10.6	11.5		
132	4/19/2013	-	-	21.7	21.7	-	12.5	13.4		
133	4/20/2013	-	-			-	13.2	14.2		
134	4/21/2013	-	-	38.2	39.4	-	24.4	26.8		
135	4/22/2013	-	-	46.8	46.4	-	32.6	35.8		
136	4/23/2013	-	-	19.0	19.8	-	12.0	12.8		
137	4/24/2013	-	-	25.7	26.0	-	16.0	17.4		
138	4/25/2013	-	-	24.9	25.4	-	15.7	17.1		
139	4/26/2013	-	-			-				
140	4/27/2013	-	-			-				
141	4/28/2013	-	-			-				
142	4/29/2013	-	-	21.5	22.6	-	14.7	15.8		
143	4/30/2013	-	-			-	17.9	19.3		
144	5/1/2013	-	-	22.4	23.4	-	20.4	22.0		
145	5/2/2013	-	-			-	21.4	23.2		
146	5/3/2013	-	-	35.6	36.7	-	29.4	32.2		
147	5/4/2013	-	-	31.7	32.5	-	22.9	24.8		
148	5/5/2013	-	-	14.8	15.7	-	10.2	10.8		
149	5/6/2013	-	-	24.9	24.7	-	17.9	19.6		
150	5/15/2013	-	-			-			Zero point	Cologne, summer

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PM10-Measured values from the field test sites, related to standard conditions [EN 12431]

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Manufacturer Comde-Derenda		PM10 and PM2,5 Measured values in µg/m³ (STD)								
Type of instrument APM-2										
Serial-No. SN 3 / SN 4										
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2 PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
151	5/16/2013	-	-			-			Zero point	Cologne, summer
152	5/17/2013	-	-	20.9	21.9	-	18.0	18.8		
153	5/18/2013	-	-			-	16.2	17.7		
154	5/19/2013	-	-			-	21.4	23.0		
155	5/20/2013	-	-	12.2	13.2	-	11.8	12.4		
156	5/21/2013	-	-	8.4	9.4	-	8.0	8.6		
157	5/22/2013	-	-	13.5	13.7	-	10.3	11.0		
158	5/23/2013	-	-	12.0	13.1	-	10.8	11.6		
159	5/24/2013	-	-	13.4	13.8	-	10.6			
160	5/25/2013	-	-			-	13.1			
161	5/26/2013	-	-	20.3	19.8	-	13.7		SN4 no data recording cause unknown	
162	5/27/2013	-	-	25.8	25.3	-	21.1	22.5		
163	5/28/2013	-	-	13.6	13.5	-	11.1	11.8		
164	5/29/2013	-	-			-	9.7	10.3		
165	5/30/2013	-	-			-	17.6	18.6		
166	5/31/2013	-	-			-	18.2	19.9		
167	6/1/2013	-	-			-	16.4	17.9		
168	6/2/2013	-	-	13.6	13.4	-	8.7	9.5		
169	6/3/2013	-	-	17.2	17.6	-	11.0	12.3		
170	6/4/2013	-	-	22.9	22.4	-	14.4	15.5		
171	6/5/2013	-	-	17.1	16.2	-	11.7	12.6		
172	6/6/2013	-	-	18.8	19.6	-	13.1	13.8		
173	6/7/2013	-	-	25.5	24.9	-	18.8	19.8		
174	6/8/2013	-	-			-	19.1	20.8		
175	6/9/2013	-	-	21.8	20.0	-	17.1	18.5		
176	6/10/2013	-	-	33.0	31.3	-	23.7	26.3		
177	6/11/2013	-	-	27.6	26.7	-	21.8	24.0		
178	6/12/2013	-	-	16.4	15.2	-	11.7	11.7		
179	6/13/2013	-	-	11.9	11.2	-	7.3	8.3		
180	6/14/2013	-	-	13.4	13.0	-	8.0	9.4		

Annex 5

PM10-Measured values from the field test sites, related to standard conditions [EN 12431]

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Manufacturer		Comde-Derenda							PM10 and PM2,5			
Type of instrument		APM-2							Measured values in µg/m³ (STD)			
Serial-No..		SN 3 / SN 4										
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2 PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site		
181	6/15/2013	-	-	13.5	13.8	-	7.4	8.8	Ref. PM2,5 - stability criteria EN 14907 not met	Cologne, summer		
182	6/16/2013	-	-	19.6	18.8	-	10.1	11.6				
183	6/17/2013	-	-	25.5	24.2	-	16.4	18.4				
184	6/18/2013	-	-	29.9	28.8	-	24.0	27.0				
185	6/19/2013	-	-	51.9	49.8	-	45.5	51.1				
186	6/20/2013	-	-	15.4	14.3	-	16.2	18.2				
187	6/21/2013	-	-	9.0	8.9	-	7.2	8.0				
188	6/22/2013	-	-	5.7	5.5	-	4.6	5.2				
189	6/23/2013	-	-	8.2	8.1	-	5.9	6.8				
190	6/24/2013	-	-	17.0	16.5	-	12.7	14.0				
191	6/25/2013	-	-	11.6	12.8	-	8.6	9.8				
192	6/26/2013	-	-	15.0	14.4	-	11.4	12.2				
193	6/27/2013	-	-	15.1	14.3	-	12.1	13.4				
194	6/28/2013	-	-	12.9	14.0	-	13.8	15.0				
195	6/29/2013	-	-			-			Zero point Zero point			
196	6/30/2013	-	-			-						
197	7/1/2013	-	-	18.4	17.9	-	13.0	14.4	Outlier Ref. PM2,5			
198	7/2/2013	-	-	15.2	14.2	-	11.4	12.1				
199	7/3/2013	-	-	12.6	12.6	-	8.9	10.0				
200	7/4/2013	-	-	16.7	15.9	-	12.0	13.1				
201	7/5/2013	-	-	25.4	24.6	-	19.9	22.0				
202	7/6/2013	-	-	19.4	18.9	-	17.7	18.8				
203	7/7/2013	-	-	17.7	17.6	-	13.4	14.2				
204	7/8/2013	-	-	19.5	19.6	-	14.0	15.6	Outlier Ref. PM10			
205	7/9/2013	-	-	25.5	25.3	-	16.3	18.3				
206	7/10/2013	-	-	19.6	19.0	-	12.4	13.5				
207	7/11/2013	-	-			-	23.4	26.0				
208	7/12/2013	-	-	30.6	28.4	-	21.9	24.4				
209	7/13/2013	-	-	28.3	26.4	-	23.0	25.0				
210	7/14/2013	-	-			-	21.8	24.3				

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PM10-Measured values from the field test sites, related to standard conditions [EN 12431]

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Manufacturer		Comde-Derenda								
Type of instrument		APM-2								
Serial-No..		SN 3 / SN 4								
PM10 and PM2,5 Measured values in µg/m³ (STD)										
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2 PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
211	7/30/2013	-	-	14.7	14.1	-	8.2	8.3		Rodenkirchen, summer
212	7/31/2013	-	-	12.9	13.2	-	8.7	8.4		
213	8/1/2013	-	-	15.8	16.6	-	10.6	10.4		
214	8/2/2013	-	-	23.2	25.3	-	15.1	15.0		
215	8/3/2013	-	-			-	10.7	10.7		
216	8/4/2013	-	-	15.3	16.1	-	9.8	9.6		
217	8/5/2013	-	-	22.3	24.4	-	13.4	12.8		
218	8/6/2013	-	-	20.1	20.6	-	12.2	11.9		
219	8/7/2013	-	-	16.2	16.3	-	12.4	12.3		
220	8/8/2013	-	-	20.0	19.6	-	13.7	14.0		
221	8/9/2013	-	-	20.0	20.4	-	13.9	14.0		
222	8/10/2013	-	-			-	11.5	11.8		
223	8/11/2013	-	-	13.5	13.2	-	8.3	8.3		
224	8/12/2013	-	-	20.0	18.8	-	10.5	10.8		
225	8/13/2013	-	-	17.5	18.0	-	10.3	10.4		
226	8/14/2013	-	-	24.4	26.3	-	12.8	13.1		
227	8/15/2013	-	-	20.5	19.9	-	12.2	12.6		
228	8/16/2013	-	-	24.2	24.3	-	14.4	14.5		
229	8/17/2013	-	-			-	9.3	8.6		
230	8/18/2013	-	-	11.5	10.9	-	7.5	7.5		
231	8/19/2013	-	-	14.9	14.8	-	9.5	9.8		
232	8/20/2013	-	-	20.4	19.8	-	14.4	14.2		
233	8/21/2013	-	-	19.9	19.0	-	17.0	16.6		
234	8/22/2013	-	-	27.3	27.5	-	21.9	22.1		
235	8/23/2013	-	-	24.8	24.8	-	20.1	20.2		
236	8/24/2013	-	-			-	26.9	26.6		
237	8/25/2013	-	-	34.8	33.1	-	30.6	31.8		
238	8/26/2013	-	-	20.5	20.6	-	14.3	14.9		
239	8/27/2013	-	-	23.5	22.2	-	17.9	17.6		
240	8/28/2013	-	-	24.3	24.9	-	22.8	22.2		

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PM10-Measured values from the field test sites, related to standard conditions [EN 12431]

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Manufacturer		Comde-Derenda								
Type of instrument		APM-2								
Serial-No..		SN 3 / SN 4								
PM10 and PM2,5 Measured values in µg/m³ (STD)										
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
241	8/29/2013	-	-	28.5	28.9	-	26.8	25.5		Rodenkirchen, summer
242	8/30/2013	-	-	29.3	31.4	-	23.8	24.3		
243	8/31/2013	-	-			-	12.2	13.2		
244	9/1/2013	-	-	19.9	20.7	-	9.5	10.6		
245	9/2/2013	-	-	22.6	24.4	-	12.4	13.8		
246	9/3/2013	-	-	24.5	25.8	-	18.2	17.7		
247	9/4/2013	-	-	15.6	16.4	-	12.2	12.3		
248	9/5/2013	-	-	17.8	20.8	-	12.6	12.3		
249	9/6/2013	-	-	33.6	36.2	-	24.3	24.9		
250	9/7/2013	-	-	25.7	26.6	-	22.1	20.6		
251	9/8/2013	-	-			-	19.5	17.6		
252	9/9/2013	-	-	11.7	12.4	-	8.9	9.0		
253	9/10/2013	-	-	11.5	11.8	-	9.2	8.3		
254	9/11/2013	-	-			-	14.8	13.5		
255	9/12/2013	-	-	24.3	25.3	-	18.8	16.3		
256	9/13/2013	-	-	15.3	15.5	-	11.1	10.2		
257	9/14/2013	-	-			-	7.3	6.8		
258	9/15/2013	-	-	15.6	16.3	-	9.1	8.0		
259	9/16/2013	-	-	15.3	15.5	-	8.1	7.4		
260	9/17/2013	-	-	13.2	13.7	-	8.9	7.5		
261	9/18/2013	-	-	23.0	23.9	-	18.3	14.2		
262	9/19/2013	-	-	17.4	18.9	-	10.9	9.9		
263	9/20/2013	-	-	21.8	21.8	-	13.1	11.9		
264	9/21/2013	-	-			-				
									Zero point	
265	1/13/2014	-	-	18.8	19.3	-	17.8	16.3		Cologne, winter 2014 validation campaign
266	1/14/2014	-	-	16.0	15.3	-	15.6	14.6		
267	1/15/2014	-	-	8.3	8.9	-	10.7	9.4		
268	1/16/2014	-	-	6.7	7.3	-	10.1	8.2		
269	1/17/2014	-	-	9.4	8.9	-	9.9	8.6		
270	1/18/2014	-	-			-	14.5	13.5		

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PM10-Measured values from the field test sites, related to standard conditions [EN 12431]

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Manufacturer Comde-Derenda		PM10 and PM2,5 Measured values in µg/m³ (STD)								
Type of instrument APM-2										
Serial-No. SN 3 / SN 4										
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2 PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
271	1/19/2014	-	-	17.5	17.7	-	20.5	18.4		Cologne, winter 2014 validation campaign
272	1/20/2014	-	-	19.4	20.2	-	23.5	21.0		
273	1/21/2014	-	-	31.5	31.4	-	30.8	28.5		
274	1/22/2014	-	-	23.3	23.5	-	24.9	22.6		
275	1/23/2014	-	-	15.5	16.4	-	16.1	16.6		
276	1/24/2014	-	-	28.6	29.0	-	28.0	29.5		
277	1/25/2014	-	-	-	-	-	15.5	15.5		
278	1/26/2014	-	-	11.8	12.3	-	12.0	12.1		
279	1/27/2014	-	-	6.9	7.2	-	8.4	7.6		
280	1/28/2014	-	-	11.3	10.8	-	11.0	11.0		
281	1/29/2014	-	-	19.7	20.0	-	19.8	20.6		
282	1/30/2014	-	-	42.5	42.7	-	44.4	46.2		
283	1/31/2014	-	-	36.3	35.8	-	36.5	37.9		
284	2/1/2014	-	-	-	-	-	10.1	9.0		
285	2/2/2014	-	-	18.5	17.6	-	18.0	18.4		
286	2/3/2014	-	-	22.6	21.9	-	22.9	23.9		
287	2/4/2014	-	-	-	-	-	17.9	18.0		
288	2/5/2014	-	-	8.3	8.5	-	9.3	9.2		
289	2/6/2014	-	-	10.3	9.5	-	9.6	8.6		
290	2/7/2014	-	-	-	-	-	-	-		
291	2/8/2014	-	-	-	-	-	-	-		
292	2/9/2014	-	-	-	-	-	-	-		
293	2/10/2014	-	-	13.5	13.5	-	14.3	14.2		
294	2/11/2014	-	-	10.0	8.2	-	8.7	8.2		
295	2/12/2014	-	-	8.6	8.1	-	9.4	8.5		
296	2/13/2014	-	-	10.7	10.2	-	9.8	9.6		
297	2/14/2014	-	-	-	-	-	7.7	7.9		
298	2/15/2014	-	-	-	-	-	8.0	7.3		
299	2/16/2014	-	-	9.1	9.4	-	9.7	9.4		
300	2/17/2014	-	-	13.0	12.7	-	12.9	12.8		

Annex 5

PM10-Measured values from the field test sites, related to standard conditions [EN 12431]

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<p>Manufacturer Comde-Derenda</p> <p>Type of instrument APM-2</p> <p>Serial-No.. SN 3 / SN 4</p> <p>PM10 and PM2,5 Measured values in µg/m³ (STD)</p>										
No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref. 2 PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 3 PM10 [µg/Nm³]	SN 4 PM10 [µg/Nm³]	Remark	Test site
301	2/18/2014	-	-	20.5	20.1	-	20.7	20.5		Cologne, winter 2014 validation campaign
302	2/19/2014	-	-	13.6	14.8	-	14.2	14.3		
303	2/20/2014	-	-	6.9	6.4	-	8.5	8.5		
304	2/21/2014	-	-	8.0	7.9	-	10.0	9.4		
305	2/22/2014	-	-	4.8	5.5	-	8.0	7.1		
306	2/23/2014	-	-	7.3	7.1	-	8.7	8.9		
307	2/24/2014	-	-	14.2	13.2	-	13.2	13.1		
308	2/25/2014	-	-	13.4	12.5	-	12.1	12.6		
309	2/26/2014	-	-	19.9	17.6	-	18.3	17.9		
310	2/27/2014	-	-	12.4	10.6	-	12.3	12.5		
311	2/28/2014	-	-	10.8	10.2	-	11.0	10.9		
312	3/1/2014	-	-	15.3	15.0	-	16.4	16.5		
313	3/2/2014	-	-	19.1	20.3	-	19.6	20.5		
314	3/3/2014	-	-	10.4	12.3	-	11.8	11.9		
315	3/4/2014	-	-	26.5	25.0	-	25.9	26.3		
316	3/5/2014	-	-	44.0	43.7	-	41.9	42.5		
317	3/6/2014	-	-	45.0	43.8	-	38.9	40.6		
318	3/7/2014	-	-	58.4	56.7	-	50.6	52.6		
319	3/8/2014	-	-	51.3	51.2	-	44.2	45.7		
320	3/9/2014	-	-	29.1	27.9	-	27.4	27.5		

Annex 6

Ambient conditions at the field test sites

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
1	11/19/2012	Cologne, winter	No weather data available					
2	11/20/2012							
3	11/21/2012							
4	11/22/2012		8.2	1013	79.5	0.6	150	0.0
5	11/23/2012		8.5	1010	88.3	0.1	147	9.3
6	11/24/2012		11.6	1005	78.5	0.9	156	0.3
7	11/25/2012		8.8	1004	70.3	1.4	161	0.3
8	11/26/2012		8.9	997	83.3	0.3	150	5.9
9	11/27/2012		7.5	998	81.2	0.1	125	0.3
10	11/28/2012		6.0	997	81.3	1.8	84	0.0
11	11/29/2012		4.0	999	81.0	1.0	80	0.0
12	11/30/2012		1.6	1005	83.8	0.1	157	0.0
13	12/1/2012		2.9	1003	83.1	0.7	156	5.1
14	12/2/2012		3.9	1006	82.3	1.3	146	0.3
15	12/3/2012		3.7	997	87.7	0.5	158	7.2
16	12/4/2012		4.5	993	84.3	1.0	114	5.7
17	12/5/2012		2.1	999	85.7	0.8	120	4.2
18	12/6/2012		0.9	1005	79.9	0.7	151	0.0
19	12/7/2012		-2.6	1001	89.4	0.0	108	0.0
20	12/8/2012		-2.6	1016	86.2	0.0	125	0.9
21	12/9/2012		4.0	1002	87.0	1.8	149	16.1
22	12/10/2012		1.9	1010	81.4	2.6	78	1.8
23	12/11/2012		-0.2	1018	74.8	0.8	128	0.0
24	12/12/2012		-0.5	1010	71.4	0.5	136	0.0
25	12/13/2012		0.9	1000	75.6	0.5	148	0.0
26	12/14/2012		7.1	988	82.4	1.3	157	4.2
27	12/15/2012		8.7	995	78.6	1.2	173	4.7
28	12/16/2012		7.2	997	85.2	0.4	151	7.4
29	12/17/2012		7.2	999	85.4	0.1	141	3.0
30	12/18/2012		6.2	1011	88.1	0.0	145	0.9

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
31	12/19/2012	Cologne, winter	4.2	1014	85.6	0.3	154	0.0
32	12/20/2012		2.8	1003	85.8	1.4	150	7.2
34	12/21/2012		6.0	1007	91.2	0.0	153	2.1
34	12/22/2012		8.7	1001	89.0	1.0	148	25.7
35	12/23/2012		10.6	1001	87.5	0.8	139	8.4
36	12/24/2012		11.8	995	76.0	0.7	155	2.4
37	12/25/2012		9.4	996	77.1	2.1	162	4.2
38	12/26/2012		9.1	1000	76.1	2.3	165	4.2
39	12/27/2012		7.3	1004	86.2	0.5	129	9.8
40	12/28/2012		8.4	1015	85.1	0.5	157	1.8
41	12/29/2012		10.4	1005	72.7	2.2	168	0.3
42	12/30/2012		8.6	1009	72.5	2.6	171	3.3
43	12/31/2012		9.9	1000	71.3	3.3	177	2.1
44	1/1/2013		6.1	1006	82.0	0.7	143	3.0
45	1/2/2013		7.5	1020	79.6	0.8	155	1.8
46	1/3/2013		10.6	1026	88.3	0.6	126	2.4
47	1/4/2013		9.1	1027	89.3	0.7	120	0.9
48	1/5/2013		8.4	1025	86.1	0.3	126	0.0
49	1/6/2013		9.1	1022	86.6	0.4	115	0.0
50	1/7/2013		8.2	1020	80.0	0.3	143	0.0
51	1/8/2013		7.6	1017	78.6	0.3	141	0.0
52	1/9/2013		5.8	1010	87.0	0.2	136	6.3
53	1/10/2013		4.0	1006	80.2	0.7	129	2.4
54	1/11/2013		-1.4	1011	78.3	0.0	153	0.0
55	1/12/2013		-1.5	1010	70.1	0.1	141	0.0
56	1/13/2013		-0.6	1009	70.0	0.2	145	0.0
57	1/14/2013		-2.5	1003	77.5	0.6	140	0.0
58	1/15/2013		-1.5	999	87.5	0.1	139	0.0
59	1/16/2013		-2.1	1006	84.8	0.0	87	0.0
60	1/17/2013		-2.0	1009	84.7	0.2	118	0.0

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
61	1/18/2013	Cologne, winter	-1.2	997	75.2	0.9	147	0.0
62	1/19/2013		-3.3	990	73.9	0.7	147	0.0
63	1/20/2013		-0.9	988	84.1	0.0	148	0.0
64	1/21/2013		-0.1	993	84.0	0.0	152	0.0
65	1/22/2013		0.2	999	80.4	0.0	149	0.0
66	1/23/2013		-0.5	1002	78.9	0.2	128	0.6
67	1/24/2013		-1.1	1010	74.4	0.6	126	0.0
68	1/25/2013		-1.9	1008	77.1	1.0	155	0.0
69	1/26/2013		-0.1	1004	81.5	0.9	148	0.6
70	1/27/2013		3.1	999	85.4	0.9	160	10.2
71	1/28/2013		6.9	1004	78.3	1.9	172	9.8
72	1/29/2013		11.9	1001	82.4	2.0	177	4.2
73	1/30/2013		10.9	1005	71.5	2.9	149	4.4
74	1/31/2013		8.6	1004	72.4	2.4	155	5.9
75	2/1/2013		5.0	990	88.1	0.9	127	11.7
76	2/2/2013		3.7	1006	78.8	1.8	94	0.9
77	2/3/2013		5.8	1006	82.0	2.0	144	3.0
78	2/4/2013		7.5	1000	76.2	1.9	149	3.3
79	2/5/2013		2.5	990	79.2	1.0	142	0.9
80	2/6/2013		2.4	997	84.5	0.9	112	5.4
81	2/27/2013	Bonn, winter	2.5	1021	78.9	0.9	185	0.0
82	2/28/2013		4.1	1017	71.8	1.2	250	0.0
83	3/1/2013		3.5	1016	72.0	1.7	249	0.0
84	3/2/2013		3.0	1015	67.4	1.2	238	0.0
85	3/3/2013		3.1	1014	72.8	0.5	196	0.0
86	3/4/2013		6.6	1007	57.8	1.4	140	0.0
87	3/5/2013		8.5	999	56.5	1.2	136	0.0
88	3/6/2013		11.5	993	48.5	0.4	143	0.0
89	3/7/2013		12.3	990	67.5	0.5	144	2.1
90	3/8/2013		13.7	990	72.1	1.4	138	1.5

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
91	3/9/2013	Bonn, winter	10.6	991	72.2	1.2	178	3.6
92	3/10/2013		1.6	993	81.8	3.6	273	2.4
93	3/11/2013		-1.4	996	78.7	1.9	241	0.0
94	3/12/2013		-3.4	995	83.9	2.0	276	0.0
95	3/13/2013		-1.2	999	72.8	1.1	224	0.3
96	3/14/2013		-1.3	1004	75.3	1.1	209	2.1
97	3/15/2013		2.3	1006	58.8	1.0	132	2.1
98	3/16/2013		5.3	998	49.0	3.4	131	0.0
99	3/17/2013		4.7	988	78.3	2.2	131	0.9
100	3/18/2013		6.6	985	60.3	0.7	131	0.0
101	3/19/2013		5.8	991	74.5	0.6	157	1.2
102	3/20/2013		2.6	999	85.8	1.9	240	13.2
103	3/21/2013		0.6	1010	78.8	1.0	229	0.3
104	3/22/2013		2.9	1006	63.4	3.2	146	0.0
105	3/23/2013		1.1	1005	56.8	4.2	146	0.0
106	3/24/2013		1.0	1005	42.8	3.3	153	0.0
107	3/25/2013		0.9	1004	49.0	2.6	153	0.0
108	3/26/2013		1.6	1003	44.1	2.3	168	0.0
109	3/27/2013		2.6	1001	49.5	2.0	148	0.0
110	3/28/2013		3.0	999	58.9	1.2	243	0.0
111	3/29/2013		0.4	999	77.8	1.1	271	1.5
112	3/30/2013		1.8	1000	68.9	1.3	271	0.0
113	3/31/2013		1.7	1003	68.2	1.1	269	0.0
114	4/1/2013		3.2	1001	52.9	1.5	190	0.0
115	4/2/2013		3.6	1003	52.2	1.8	201	0.0
116	4/3/2013		3.0	1005	58.0	1.8	158	0.0
117	4/4/2013		4.4	1001	60.5	1.8	166	0.0
118	4/5/2013		3.8	1003	67.8	1.6	267	0.0
119	4/6/2013		3.6	1012	73.9	1.7	221	0.3
120	4/7/2013		6.4	1008	51.4	0.7	174	0.0

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
121	4/8/2013	Bonn, winter	7.0	996	63.9	1.4	130	0.9
122	4/9/2013		8.3	992	78.0	1.2	133	1.8
123	4/10/2013		9.7	996	77.3	1.4	154	6.0
124	4/11/2013		13.0	991	69.6	1.3	169	6.0
125	4/12/2013		12.2	997	69.0	1.1	154	4.4
126	4/13/2013		13.9	1011	56.8	1.4	152	0.6
127	4/14/2013		18.3	1011	57.0	1.5	136	0.0
128	4/15/2013		17.5	1011	67.0	1.5	214	2.7
129	4/16/2013		18.4	1011	54.4	0.9	149	0.0
130	4/17/2013		18.7	1009	54.3	0.6	141	0.0
131	4/18/2013		15.6	1009	46.2	3.1	210	0.0
132	4/19/2013		11.4	1017	57.7	3.5	260	0.0
134	4/20/2013		10.3	1018	51.5	3.3	274	0.0
134	4/21/2013		11.1	1009	57.4	1.1	253	0.0
135	4/22/2013		13.2	1009	46.5	1.4	217	0.0
136	4/23/2013		13.7	1014	63.6	1.7	187	0.0
137	4/24/2013		17.9	1016	56.5	1.0	167	0.0
138	4/25/2013		20.0	1010	51.5	0.4	146	0.0
139	4/26/2013		11.9	1000	77.3	2.2	230	9.9
140	4/27/2013		7.8	1003	70.3	3.2	293	0.0
141	4/28/2013		9.2	1007	68.3	0.7	169	0.0
142	4/29/2013		12.0	1010	56.1	1.9	209	0.0
143	4/30/2013		11.8	1014	57.9	1.0	214	0.0
144	5/1/2013		14.6	1011	62.8	0.9	173	0.3
145	5/2/2013		16.5	1009	60.4	1.1	200	0.0
146	5/3/2013		16.0	1007	60.0	1.5	253	0.0
147	5/4/2013		15.7	1011	54.5	2.4	238	0.0
148	5/5/2013		16.4	1013	55.9	1.3	190	0.0
149	5/6/2013		19.8	1008	50.0	0.6	192	0.0
150	5/15/2013	Cologne, summer	No weather data available					

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
151	5/16/2013	Cologne, summer	No weather data available					
152	5/17/2013		9.9	997	86.2	0.7	173	0.6
153	5/18/2013		12.1	1001	74.2	0.1	140	0.0
154	5/19/2013		17.1	998	64.4	1.5	203	12.1
155	5/20/2013		11.4	1001	83.5	0.3	172	3.3
156	5/21/2013		12.7	1002	78.2	1.4	185	21.3
157	5/22/2013		8.5	1004	79.4	1.4	172	12.7
158	5/23/2013		6.3	1001	80.7	0.9	205	1.5
159	5/24/2013		8.4	1004	67.0	0.2	149	0.0
160	5/25/2013		10.5	1005	71.3	1.9	176	9.8
161	5/26/2013		9.7	1003	79.2	2.7	195	6.5
162	5/27/2013		14.1	1000	61.6	0.9	170	0.0
163	5/28/2013		18.0	993	58.8	1.3	166	0.9
164	5/29/2013		9.2	996	89.4	0.6	164	25.2
165	5/30/2013		13.9	1000	68.4	0.4	196	0.3
166	5/31/2013		16.1	1002	70.0	2.3	197	0.0
167	6/1/2013		11.6	1011	76.2	2.2	187	0.0
168	6/2/2013		13.7	1017	54.1	2.4	213	0.0
169	6/3/2013		13.2	1018	58.9	2.0	195	0.0
170	6/4/2013		16.3	1012	63.2	0.8	189	0.0
171	6/5/2013		20.1	1010	53.6	0.2	172	0.0
172	6/6/2013		21.1	1011	51.4	0.2	182	0.0
173	6/7/2013		23.0	1010	51.4	0.3	186	0.0
174	6/8/2013		20.8	1005	60.2	1.1	163	0.0
175	6/9/2013		15.9	1002	71.7	1.0	199	2.4
176	6/10/2013		15.1	1006	70.0	0.5	193	0.0
177	6/11/2013		19.8	1009	57.4	0.2	176	0.0
178	6/12/2013		21.2	1008	66.3	0.3	151	0.3
179	6/13/2013		16.2	1008	77.3	1.4	158	20.4
180	6/14/2013		15.8	1009	65.6	0.1	200	0.0

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
181	6/15/2013	Cologne, summer	16.8	1006	60.6	1.1	172	0.0
182	6/16/2013		18.1	1007	61.0	0.3	159	0.0
183	6/17/2013		23.6	1005	64.7	0.2	186	0.6
184	6/18/2013		28.2	1005	57.4	0.2	181	0.0
185	6/19/2013		27.2	1003	64.4	1.1	190	0.0
186	6/20/2013		19.7	1003	79.5	0.4	187	32.4
187	6/21/2013		17.9	1006	73.8	0.7	155	2.7
188	6/22/2013		18.4	1004	67.4	1.0	172	2.4
189	6/23/2013		16.0	1006	69.7	1.6	176	1.5
190	6/24/2013		13.7	1014	76.2	1.8	163	0.3
191	6/25/2013		13.0	1019	68.8	0.9	232	0.0
192	6/26/2013		13.6	1018	71.0	0.7	197	11.2
193	6/27/2013		12.6	1014	77.9	0.4	191	8.9
194	6/28/2013		13.7	1010	89.5	0.2	173	22.5
195	6/29/2013		13.8	1014	74.0	1.1	222	0.0
196	6/30/2013		17.6	1012	67.3	0.5	163	0.0
197	7/1/2013		19.4	1008	68.3	0.4	189	0.0
198	7/2/2013		21.8	1003	59.2	0.2	179	0.9
199	7/3/2013		16.9	1005	87.7	0.1	179	12.7
200	7/4/2013		20.4	1015	68.6	0.6	187	0.0
201	7/5/2013		19.9	1021	73.4	0.3	186	0.0
202	7/6/2013		22.9	1020	61.9	0.2	147	0.0
203	7/7/2013		23.6	1021	54.0	0.7	174	0.0
204	7/8/2013		24.0	1019	55.0	0.8	156	0.0
205	7/9/2013		23.4	1014	55.6	0.8	207	0.0
206	7/10/2013		19.1	1012	61.2	2.0	191	0.0
207	7/11/2013		14.8	1014	73.1	0.4	174	0.0
208	7/12/2013		16.8	1014	68.2	0.7	184	0.0
209	7/13/2013		18.0	1015	66.5	0.5	196	0.0
210	7/14/2013		No weather data available					

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
211	7/30/2013	Rodenkirchen, summer	18.2	1006	80.0	2.4	201	7.3
212	7/31/2013		20.1	1006	75.8	3.4	233	0.0
213	8/1/2013		24.0	1004	62.5	2.9	117	0.0
214	8/2/2013		27.8	1000	48.6	3.4	128	2.7
215	8/3/2013		23.1	1006	64.3	3.3	230	0.0
216	8/4/2013		20.5	1009	64.3	1.6	122	0.0
217	8/5/2013		22.8	1004	62.3	2.6	128	0.1
218	8/6/2013		21.6	1003	62.9	2.7	213	0.0
219	8/7/2013		19.5	999	80.7	2.9	175	1.2
220	8/8/2013		16.8	1006	82.9	2.4	233	0.7
221	8/9/2013		17.9	1008	73.5	1.8	174	0.0
222	8/10/2013		17.3	1008	71.8	3.0	241	0.0
223	8/11/2013		17.0	1007	62.9	2.5	199	0.0
224	8/12/2013		16.9	1004	75.3	2.3	202	0.4
225	8/13/2013		15.5	1007	73.7	2.9	217	0.0
226	8/14/2013		14.5	1011	75.3	1.8	161	0.0
227	8/15/2013		17.2	1010	73.1	2.0	151	0.0
228	8/16/2013		20.9	1005	59.1	2.4	167	0.0
229	8/17/2013		21.4	1003	65.8	2.1	226	0.0
230	8/18/2013		19.6	1001	81.0	3.2	174	7.8
231	8/19/2013		16.9	1005	83.0	3.2	263	0.5
232	8/20/2013		14.3	1016	78.9	1.6	154	0.0
234	8/21/2013		15.5	1013	70.6	1.7	141	0.0
234	8/22/2013		18.2	1008	65.3	1.8	154	0.0
235	8/23/2013		20.3	1005	62.3	2.4	128	0.0
236	8/24/2013		17.8	1000	80.0	2.7	135	5.9
237	8/25/2013		16.2	1000	96.4	1.6	224	2.5
238	8/26/2013		16.1	1003	81.8	1.7	141	0.0
239	8/27/2013		17.1	1003	69.7	1.7	142	0.0
240	8/28/2013		15.7	1007	78.3	1.6	166	0.0

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
241	8/29/2013	Rodenkirchen, summer	17.0	1010	72.2	1.8	146	0.0
242	8/30/2013		17.1	1008	72.8	1.8	189	0.0
243	8/31/2013		16.4	1009	81.1	2.7	244	2.0
244	9/1/2013		13.9	1015	70.5	2.9	256	0.0
245	9/2/2013		17.1	1013	70.7	3.5	269	0.0
246	9/3/2013		17.2	1015	82.2	1.6	145	0.0
247	9/4/2013		20.5	1010	70.6	2.0	112	0.0
248	9/5/2013		23.6	1002	61.5	3.6	126	0.0
249	9/6/2013		23.7	998	60.2	3.6	166	0.0
250	9/7/2013		17.9	1005	88.0	2.2	225	21.3
251	9/8/2013		14.0	1007	94.6	2.5	244	2.1
252	9/9/2013		14.0	1005	80.5	2.8	186	2.7
253	9/10/2013		12.8	1001	81.3	5.0	255	9.2
254	9/11/2013		12.8	1001	91.5	3.2	270	5.8
255	9/12/2013		13.5	1004	92.0	2.5	277	7.2
256	9/13/2013		15.2	1008	84.4	2.0	194	1.0
257	9/14/2013		15.3	1001	91.0	3.1	214	3.8
258	9/15/2013		13.7	999	79.4	2.3	280	8.1
259	9/16/2013		12.8	990	72.3	4.3	238	0.0
260	9/17/2013		9.9	991	81.7	3.8	184	5.8
261	9/18/2013		11.7	988	92.8	2.7	270	1.2
262	9/19/2013		12.3	1000	79.4	2.7	225	1.8
263	9/20/2013		13.8	1004	83.7	2.9	248	0.0
264	9/21/2013		12.9	1014	83.8	1.2	165	0.0
265	1/13/2014	Cologne, winter 2014 validation campaign	6.8	1002	82.5	0.0	210	0.0
266	1/14/2014		6.3	1001	77.9	0.3	203	0.0
267	1/15/2014		5.3	998	86.2	0.3	205	3.9
268	1/16/2014		7.8	993	80.2	0.2	220	0.0
269	1/17/2014		8.2	994	72.4	0.3	209	0.3
270	1/18/2014		6.5	992	75.3	0.7	202	0.0

Report on performance testing of the Air Pollution Monitor 2 (APM-2) measuring system manufactured by Comde-Derenda GmbH for the components suspended particulate matter PM10 and PM2.5, Report no.: 936/21219977/A

Annex 6

Ambient conditions at the field test sites

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
271	1/19/2014	Cologne, winter 2014 validation campaign	5.7	994	80.7	0.2	202	0.0
272	1/20/2014		3.8	1000	83.9	0.3	135	0.0
273	1/21/2014		4.0	1005	87.1	0.0	186	0.0
274	1/22/2014		2.7	1006	84.8	0.1	203	0.0
275	1/23/2014		3.8	1004	87.2	0.2	193	8.0
276	1/24/2014		4.1	1010	86.2	0.0	188	0.3
277	1/25/2014		5.0	1004	79.5	1.1	208	6.5
278	1/26/2014		5.1	991	79.6	0.8	207	18.9
279	1/27/2014		4.9	990	75.6	0.8	214	0.3
280	1/28/2014		3.8	992	73.6	0.6	204	0.0
281	1/29/2014		2.6	996	71.0	1.1	198	0.0
282	1/30/2014		2.5	1000	72.6	0.2	194	0.0
283	1/31/2014		5.7	996	70.7	0.6	204	0.3
284	2/1/2014		5.5	997	81.6	0.5	214	3.6
285	2/2/2014		4.2	1008	76.5	0.5	207	0.0
286	2/3/2014		4.9	1001	77.9	0.7	203	0.0
287	2/4/2014		5.9	998	75.1	0.3	204	0.0
288	2/5/2014		7.4	992	73.8	1.2	209	0.0
289	2/6/2014		10.2	989	66.1	1.6	210	5.1
290	2/7/2014		7.6	991	72.7	2.4	216	7.7
291	2/8/2014		7.7	984	70.0	1.9	219	0.6
292	2/9/2014		5.9	989	67.2	1.7	221	0.0
293	2/10/2014		5.5	990	75.2	0.3	205	1.8
294	2/11/2014		6.7	997	70.1	1.1	217	2.4
295	2/12/2014		7.1	994	68.5	1.7	224	0.3
296	2/13/2014		5.2	992	80.2	0.5	201	8.0
297	2/14/2014		8.6	992	74.6	1.4	217	9.5
298	2/15/2014		10.0	995	65.2	3.0	210	1.5
299	2/16/2014		7.4	1004	71.7	0.8	220	0.6
300	2/17/2014		4.2	1008	82.8	0.0	212	0.0

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Ambient conditions at the field test sites

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No.	Date	Test site	Ambient temperature (AVG) [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
301	2/18/2014	Cologne, winter 2014 validation campaign	7.4	1005	76.0	0.1	214	1.8
302	2/19/2014		8.3	1006	77.5	0.3	208	0.0
303	2/20/2014		9.7	999	78.3	0.9	209	5.4
304	2/21/2014		5.8	1002	77.2	0.6	207	0.9
305	2/22/2014		5.5	1010	76.2	0.7	211	1.8
306	2/23/2014		7.3	1011	70.4	0.5	206	0.0
307	2/24/2014		12.9	1005	53.2	0.5	203	0.0
308	2/25/2014		No weather data available					
309	2/26/2014							
310	2/27/2014							
311	2/28/2014		6.6	994	75.3	0.3	199	0.0
312	3/1/2014		5.8	995	78.1	0.1	223	0.6
313	3/2/2014		6.1	990	69.9	0.7	199	0.0
314	3/3/2014		6.2	988	71.5	0.6	187	0.0
315	3/4/2014		7.9	1002	70.6	0.1	199	0.0
316	3/5/2014		4.6	1018	81.8	0.2	146	0.0
317	3/6/2014		7.6	1020	67.2	0.2	191	0.0
318	3/7/2014		11.1	1021	63.3	0.1	178	0.0
319	3/8/2014		12.4	1022	56.2	0.5	202	0.0
320	3/9/2014		13.1	1020	46.8	0.3	164	0.0

Appendix 2

Filter weighing procedure

A.1 Carrying out the weighing

All weighings are done in an air-conditioned weighing room. Ambient conditions are 20 °C \pm 1 °C and 50 % \pm 5 % relative humidity, which conforms to the requirements of Standard EN 14907.

The filters used in the field test are weighed manually. In order to condition the filters (including control filters), they are placed on sieves to avoid overlap.

The specifications for pre- and post-weighing are specified beforehand and conform to the Standard.

Before sampling = pre-weighing	After sampling = post-weighing
Conditioning 48 h + 2 h	Conditioning 48 h + 2 h
Filter weighing	Filter weighing
Re-conditioning 24 h + 2 h	Re-conditioning 24 h + 2 h
Filter weighing and immediate packaging	Filter weighing

The balance is always ready for use. An internal calibration process is started prior to each weighing series. The standard weight of 200 mg is weighed as reference and the boundary conditions are noted down if nothing out of the ordinary results from the calibration process. Deviations of prior weighings conform to the Standard and do not exceed 20 µg (refer to Figure 1). All six control filters are weighed afterwards and a warning is displayed for control filters with deviations > 40 µg during evaluation. These control filters are not used for post-weighing. Instead, the first three acceptable control filters are used while the others remain in the protective jar in order to replace a defective or deviating filter, if necessary. Figure 2 shows an exemplary process over a period of more than four months.

All filters which display a difference of more than 40 µg between the first and second weighing are excluded from the pre-weighing process. Filters exhibiting deviations of more than 60 µg are not considered for evaluation after post-weighing, as conforming to standards.

Weighed filters are packed in separate polystyrene jars for transport and storage. These jars remain closed until the filter is inserted. Virgin filters can be stored in the weighing room for up to 28 days before sampling. Another pre-weighing is carried out if this period is exceeded.

Sampled filters can be stored for up to 15 days at a temperature of 23 °C or less. The filters are stored at 7 °C in a refrigerator.

A2 Filter evaluation

The filters are evaluated with the help of a corrective term in order to minimize relative mass changes caused by the weighing room conditions.

Equation:

$$\text{Dust} = \text{MF}_{\text{post}} - (\text{M}_{\text{Tara}} \times (\text{MKon}_{\text{post}} / \text{MKon}_{\text{pre}})) \quad (\text{F1})$$

MKon_{pre} = mean mass of the 3 control filters after 48 h and 72 h pre-weighing

$\text{MKon}_{\text{post}}$ = mean mass of the 3 control filters after 48 h and 72 h post-weighing

M_{Tara} = mean mass of the filter after 48 h and 72 h pre-weighing

MF_{post} = mean mass of the loaded filter after 48 h and 72 h post-weighing

Dust = corrected dust mass of the filter

This shows that the method becomes independent from weighing room conditions due to the corrective calculation. Influence due to the water content of the filter mass between virgin and loaded filter can be controlled and do not change the dust content of sampled filters. Hence, point 9.3.2.5 of EN 14907 is fulfilled.

The example of the standard weight between November 2008 and February 2009 shows that the permissible difference of max. 20 µg from the previous measurement is not exceeded.

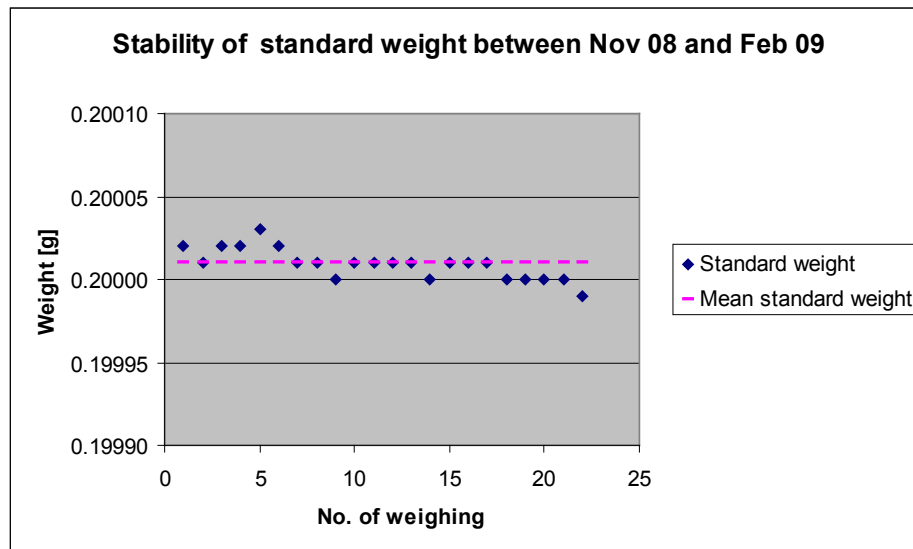


Figure 1: Stability of standard weight

Table 1: *Stability of standard weight*

Date	Weighing No.	Standard weight g	Difference to the previous weighing µg
12.11.2008	1	0.20002	
13.11.2008	2	0.20001	-10
10.12.2008	3	0.20002	10
11.12.2008	4	0.20002	0
17.12.2008	5	0.20003	10
18.12.2008	6	0.20002	-10
07.01.2009	7	0.20001	-10
08.01.2009	8	0.20001	0
14.01.2009	9	0.20000	-10
15.01.2009	10	0.20001	10
21.01.2009	11	0.20001	0
22.01.2009	12	0.20001	0
29.01.2009	13	0.20001	0
30.01.2009	14	0.20000	-10
04.02.2008	15	0.20001	10
05.02.2009	16	0.20001	0
11.02.2009	17	0.20001	0
12.02.2009	18	0.20000	-10
18.02.2009	19	0.20000	0
19.02.2009	20	0.20000	0
26.02.2009	21	0.20000	0
27.02.2009	22	0.19999	-10

Marked in yellow = average value

Marked in green = lowest value

Marked in blue = highest value

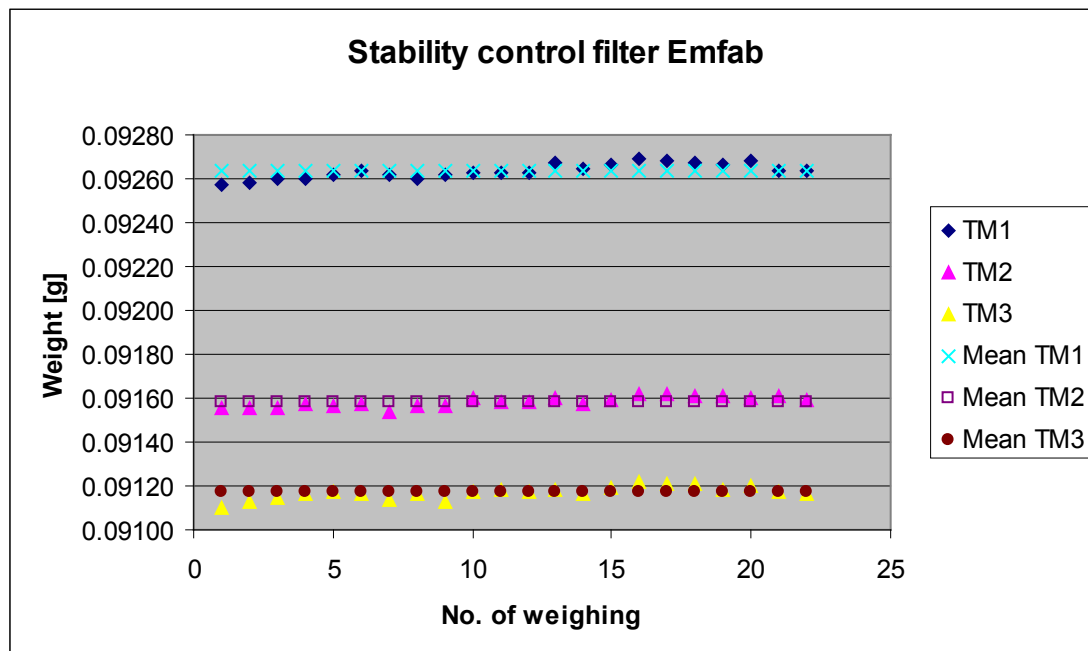


Figure 2: Stability of the control filters

Table 2: *Stability of the control filters*

Weighing no.	Control filter no.		
	TM1	TM2	TM3
1	0.09257	0.09155	0.09110
2	0.09258	0.09155	0.09113
3	0.09260	0.09155	0.09115
4	0.09260	0.09157	0.09116
5	0.09262	0.09156	0.09117
6	0.09264	0.09157	0.09116
7	0.09262	0.09154	0.09114
8	0.09260	0.09156	0.09116
9	0.09262	0.09156	0.09113
10	0.09263	0.09160	0.09117
11	0.09263	0.09158	0.09118
12	0.09263	0.09158	0.09117
13	0.09267	0.09160	0.09118
14	0.09265	0.09157	0.09116
15	0.09266	0.09159	0.09119
16	0.09269	0.09162	0.09122
17	0.09268	0.09162	0.09121
18	0.09267	0.09161	0.09121
19	0.09266	0.09161	0.09118
20	0.09268	0.09160	0.09120
21	0.09264	0.09161	0.09117
22	0.09264	0.09159	0.09116
Mean value	0.09264	0.09158	0.09117
Standard deviation.	3.2911E-05	2.4937E-05	2.8558E-05
Rel. standard deviation.	0.036	0.027	0.031
Median	0.09264	0.09158	0.09117
Lowest value	0.09257	0.09154	0.09110
Highest value	0.09269	0.09162	0.09122

Marked in yellow = average value

Marked in green = lowest value

Marked in blue = highest value

Report on performance testing of the Air Pollution Monitor 2 (APM-2) measuring system manufactured by Comde-Derenda GmbH for the components suspended particulate matter PM₁₀ and PM_{2.5}, Report no.: 936/21219977/A

Appendix 3

Manual

Instruction Manual

Air Pollution Monitor 2 (APM-2)



Important Information

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Authority to adopt changes to this instruction manual and the system software as well as modifications to the technology, equipment and form of the device in comparison with the statements and illustrations in this manual is reserved by the Comde-Derenda GmbH; such changes may be implemented without prior notification.

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Comde-Derenda GmbH
Kieler Strasse 9
14532 Stahnsdorf, Germany
Tel.: +49 3329 69027-10
Fax: +49 3329 69027-19
E-Mail: info@derenda.de
www.derenda.de

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1. Introduction

This instruction manual is intended to provide a systematic and comprehensive introduction to the features, functions and operation of the sampling system. This manual also contains a number of important safety warnings. Please read this manual completely and carefully so that you will be able to make use of the system's many functions and do so both safely and efficiently. Please note that details in the description of the device and in the illustrations may deviate from the properties found in your own unit.

1.1. Symbols and Typography

In the interest of making the text clearer and more understandable, the following symbols and typographic conventions are used.

The following apply to sections that deal with the parameterization and control of the device by way of the control unit:

- Elements that can be clicked or selected (e.g. menu items) are highlighted in blue
- Other words appearing in software screens are **boldfaced**
- Instructions regarding elements to be selected in sequence sometimes use arrows in the interest of brevity (e.g. Settings → Language → English)

The following apply to safety information:



DANGER!

This symbol indicates risk to life, serious injury and/or considerable property damage if the appropriate safety measures are not taken



WARNING!

This symbol indicates risk of lesser injury and property damage if the appropriate safety measures are not taken

WARNING!

without a warning triangle indicates a risk to property if the appropriate safety measures are not taken

CAUTION!

indicates that undesirable results or states could occur if the appropriate notes are not observed

NOTE:

indicates important information or emphasizes a part of the documentation to which particular attention must be paid

1.2. Intended Use

The sampling system may be used only for the purposes specified in this manual and only in conjunction with devices and components recommended and approved by the Comde-Derenda GmbH.

1.3. Operating Environment

The device is designed for operation at temperatures of from -20°C to +50°C. In the case of extended exposure to strong sunlight in conjunction with very high air temperatures (upwards of about 35°C), the system is to be set up beneath a self-supporting roof with an opening through which the air intake tube passes. The APM-2 is designed for outdoor use and may be operated without rain protection or the like.

1.4. Electromagnetic Compatibility

This is a Class A unit and may cause radio interference in residential areas. In this event the operator may be required to implement and pay for appropriate abatement measures. The device satisfies the requirements of the Electromagnetic Compatibility (EMC) Directive and harmonized European standards. Every modification to the system may have an effect on EMC characteristics.

1.5. Scope of Delivery

Included in the delivery are:

- 1 each Basic device APM-2
- 1 each Air intake tube (length 500 mm, diameter 12 mm)
- 1 each Impactor inlet PM₁₀
- 1 each Serial cable for connection to a PC
- 2 each SD memory card
- 1 each USB card reader
- 1 each Instruction manual
- 1 each Calibration record
- 1 each Set of keys for the equipment

2. Safety Instructions

This unit was engineered and tested in accordance with DIN EN 61010-1:2002-08 (Safety requirements for electrical equipment for measurement, control and laboratory use). It left the factory in perfect working condition. In order to maintain this condition and to ensure hazard-free operation please be absolutely sure to observe the following safety notes. Disregarding these warnings or noncompliance with these notes could result in fatalities, severe bodily injury and/or significant property damage. Also observe local safety requirements that govern dealings with electrical and electronic equipment carrying line voltage. Although the device was manufactured in accordance with recognized safety regulations, hazards or adverse effects for the unit or other property could arise during use.

Only suitably qualified personnel may work on this unit. This personnel shall be thoroughly familiar with all the safety notes and with the installation, operation and maintenance procedures contained in this instruction manual. Safe and fault-free operation of the unit presumes proper handling and correct installation, operation and maintenance.

This device may be used only for the purpose intended by Comde-Derenda GmbH (see 1.2). Unauthorized modifications and the use of accessories and spare parts not supplied or recommended by Comde-Derenda GmbH can result in property damage and personal injury.



WARNING!

If it is to be expected that hazard-free operation is no longer possible, then the device shall be taken out of service and secured against unintentional restarting.

It is to be presumed that non-hazardous operation is no longer possible:

- if the electronics unit exhibits visible damage
- if the unit no longer operates or shows obvious deviations from normal operations
- if an electrical connector has been damaged

As long as the unit is connected to the line power supply components carrying electrical voltage may become accessible when covers are opened or other parts are removed.



WARNING!

- The unit must be disconnected from all sources of electrical power prior to starting maintenance or repairs or replacing parts.
- Whenever it is unavoidable to carry out maintenance or repair work on devices that are opened and connected to the power supply, then such work may be carried out only by a qualified employee who is familiar with all the associated hazards.
- Any interruption in the protective ground wire either inside or outside the unit or disconnection of the ground wire may result in the unit becoming dangerous. Any intentional interruption of the ground wire circuit is prohibited!

- The line plug may be connected only to a socket with a protective ground contact. This safety feature may not be counteracted by using an extension cord that does not incorporate a protective ground wire.

3. System Overview

The APM-2 is a measuring device for direct and continuous determination of the suspended particulate matter of the fractions PM_{10} and $PM_{2.5}$ in outside air. The heart of the device is a highly sensitive scattered light photometer. The measuring method applied makes use of the specific physical features of light scattering in microparticles.

3.1. Functional Concept

Outside air is drawn in via a PM_{10} impactor inlet at a volume flow of 3.3 l/min. Particles larger than 10 μm are separated in this impactor inlet. In a virtual impactor the air drawn in is then divided into two partial flows. The aerosol now optionally goes from the axial flow (enrichment mode for recording PM_{10} concentration) or from the side flow (normal mode for recording $PM_{2.5}$ concentration) to the scattered light sensor system via solenoid valves.

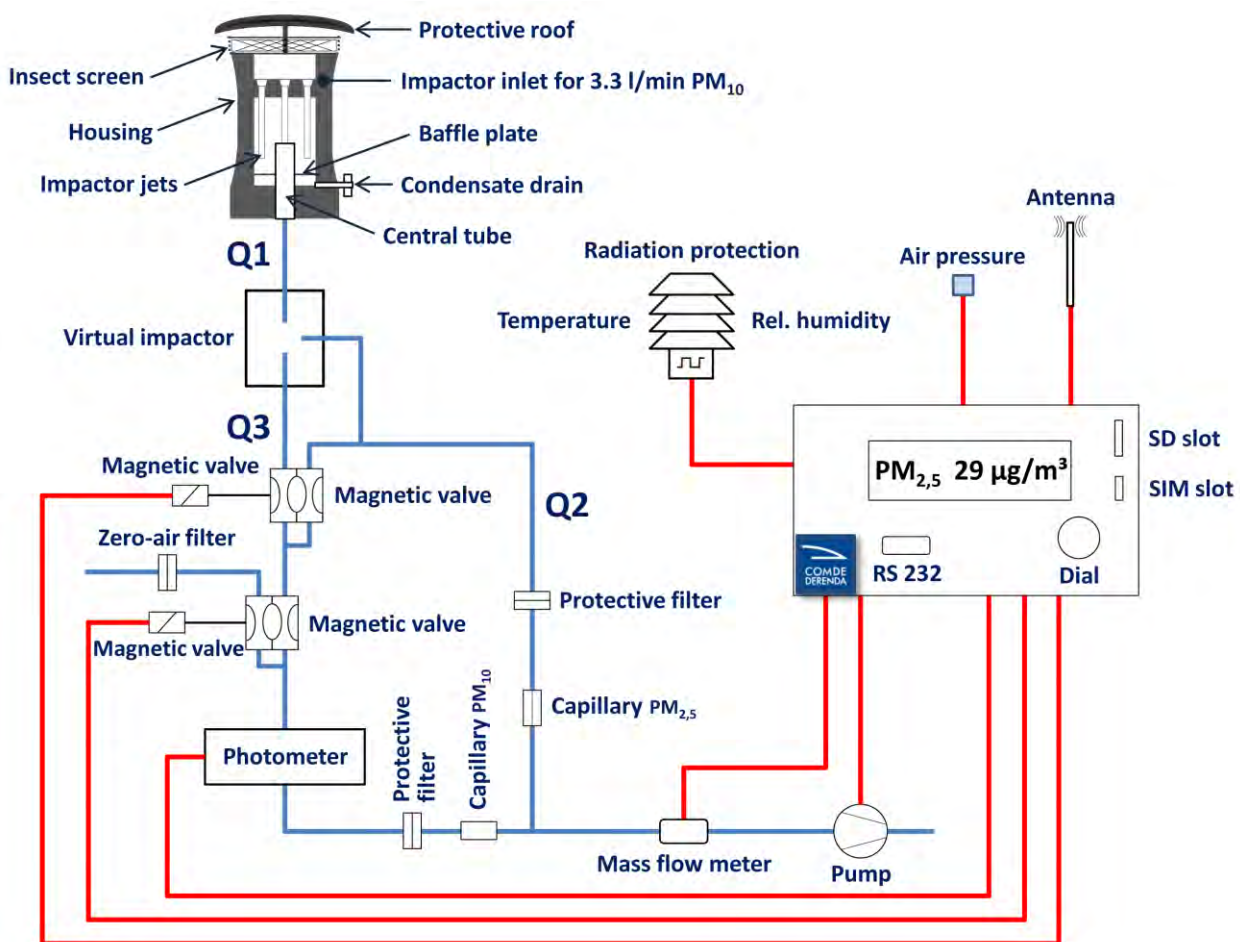


Fig. 1: Overview diagram

The light of a laser diode illuminates there a measurement volume defined by the optical beam path. The light reflected by the aerosol particles within this measurement volume is recorded by the detector positioned at an angle of 90°. The voltage signal generated and then amplified by the detector represents a direct measure for the mass concentration of the aerosol in the measurement volume (0-1000 $\mu\text{g}/\text{m}^3$). For the zero point adjustment, filtered air is fed to the scattered light sensor via the switching device at periodic intervals. The data determined are stored in the device memory as well as – if provided – on an SD memory card.

The physics of the light scattering on particulates causes aerosol particles with a diameter on the order of the light wavelength used – based on their mass – to scatter the light the most efficiently. That means they supply the greatest contribution to the signal. The maximum sensitivity for the wavelength of 650 nm used in the device is in a particle size range from 0.5 to 1 μm . Because of this characteristic, there are limits to application of simple scattered light photometry for measurement of the PM_{10} concentration. The measurement signal of a scattered light sensor used in outside air is primarily dominated by the $\text{PM}_{2.5}$ fraction.



Fig. 2: Front side of APM-2

Based on mass, the complementary coarse fraction $\text{PM}_{2.5-10}$ contributes significantly less to the scattered light signal and is therefore underrepresented in the measurement. The sensitivity deficit in the coarse fraction is thus compensated for in the device by a simple process: via selective enrichment of the concentration of the $\text{PM}_{2.5-10}$ fraction by a factor of $3.3/0.2=16.5$ by means of a virtual impactor (see 3.1.3.), which is connected upstream from the scattered light sensor. Concentration enrichment is equivalent to an increase in sensitivity of the photometry for the $\text{PM}_{2.5-10}$ fraction.

The system consists of the following components:

3.1.1. Control Unit

All the system settings are entered at the APM-2 control unit (Fig. 3). The unit has the following elements and functions:

- Main switch used to switch the unit on and off
- Log dial to select functions and to enter or change parameters
- An illuminated graphic display showing system functions, parameters, data and alarms
- SD memory card slot for automatic storage of sampling data and parameters and for updating the equipment firmware (also for the filter changer unit)

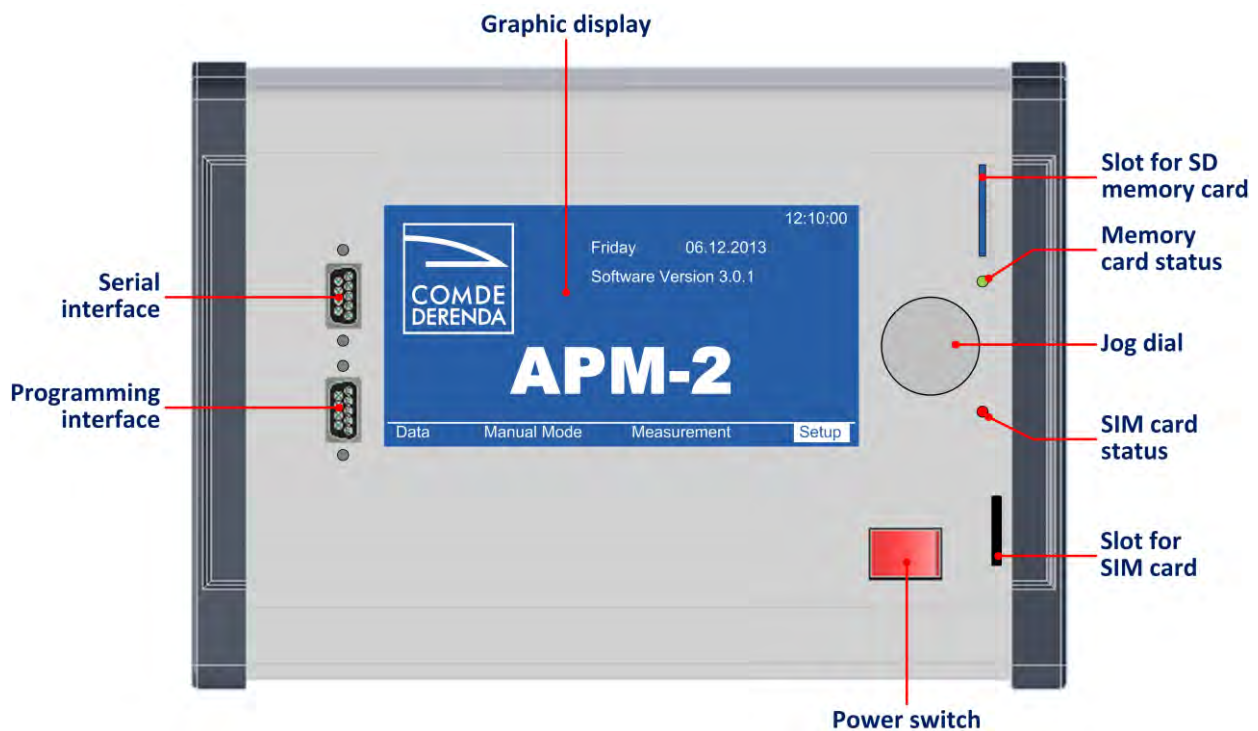


Fig. 3: Control unit

- Programming interface , exclusively for programming purposes; can not be used for data transmission
- Serial interface (RS-232) for data transfer as per the Bayern-Hessen-Protokoll (Bavaria-Hesse protocol)
- Status indicator for the SD memory card:
 - Green = Memory card is on standby
 - Red = Reading from or writing to the memory card
 - Orange = Firmware update being transferred to internal flash memory
 - Dark = No memory card installed
- GSM/GPRS module with SIM card slot for online data transmission via mobile phone network (optional)
- Status indicator for the GSM/GPRS module (slow blink, rapid blink, steady light)



Fig. 4: External sensor

3.1.2. External Sensor

The unit's external sensor (Fig. 4) is used for continuous registration of temperature and relative humidity. The ambient temperature is measured at an accuracy of ± 0.5 K in a range of from -40 to $+80$ °C, relative humidity at an accuracy of ± 3 % in a range of from 0 to 100 %.

The sensor is bolted to the unit by way of a mounting bracket (for assembly instruction see 4.3). A shield protects the sensor from direct sunlight and precipitation.

3.1.3. Virtual Impactor

The virtual impactor is located on the top side of housing and is connected to the impactor inlet via the intake tube. The outside air drawn in by means of an integrated pump at 3.3 l/min is divided into two partial flows by the virtual impactor. This division takes place in the area around two jets mounted opposite each other. In this process the side flow (3.1 l/min) is drawn off between the two jets perpendicular to the incoming air flow. Particles that cannot follow the side flow because of their mass inertia extensively maintain their direction of motion and thus enter the smaller axial flow (0.2 l/min). This results in the division into the side flow with exclusively smaller and lighter particles of the $PM_{2.5}$ fraction and the axial flow with a particle size of PM_{10} . The aerosol now goes optionally from the axial flow (enrichment mode) or from the side flow (normal mode) to the scattered light sensor via low-loss switching devices (pinch valves with straight passage). In the enrichment mode the APM-2 thus records the PM_{10} concentration, in normal mode the $PM_{2.5}$ concentration. For zero point adjustment, filtered light is fed to the scattered light sensor via the switching device at periodic intervals.

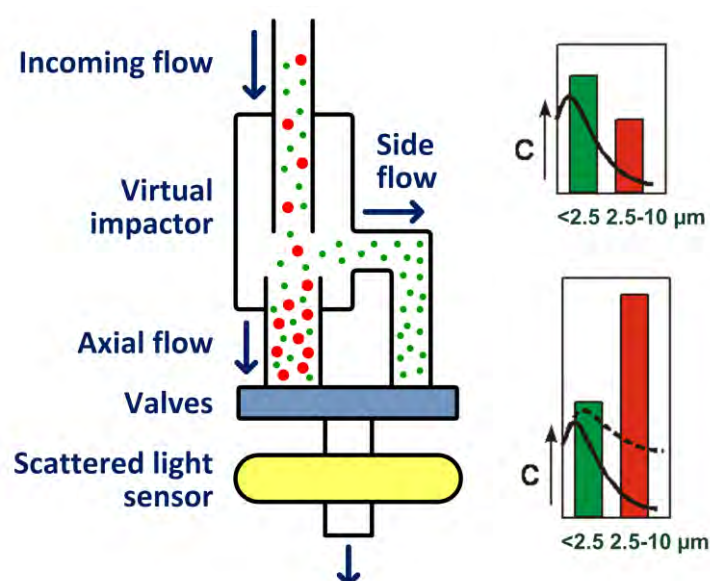


Fig. 5: Functional principle of the virtual impactor

3.1.4. Scattered Light Photometer Unit

The photometer unit consists of an intensity-stabilized laser diode and a semiconductor photodetector. The two components are mounted at an angle of 90° to each other, the unit is thus a single-angle sensor. The light reflected by the particles in a precisely defined measurement volume is recorded by the detector as described in 0. The photodetector then generates a corresponding voltage signal (0-5 V), which is subsequently amplified in a low-noise process.

To rule out temperature dependence of the photometer signal, the photometer is installed in a thermally insulated housing heated with a heating block and temperature-controlled to 40°C.

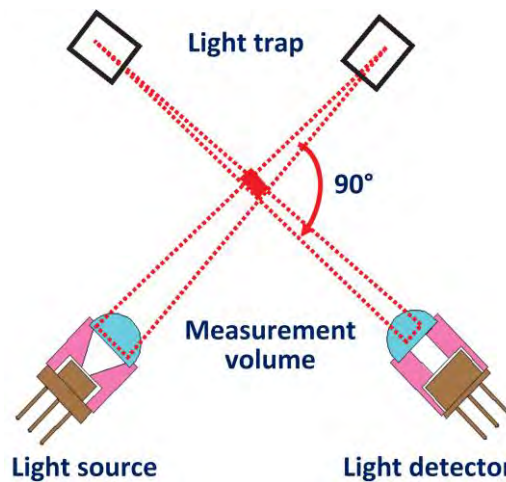


Fig. 6: Functional principle of the photometer unit

3.1.5. Impactor Inlet and Intake Tube



Fig. 7: APM-2 impactor inlet

Particles larger than 10 µm are separated by the PM₁₀ impactor inlet (Fig. 7) during intake. In terms of its design it corresponds to the certified Derenda PM₁₀ sampling inlet in accordance with DIN EN 12541. It was scaled down from 38.3 l/min to the smaller intake volume flow of 3.3 l/min for application in the APM-2. The impactor inlet is mounted on the intake tube that leads to the virtual impactor on the device roof.

The impactor inlet and the APM-2 are connected to each other via an intake tube made of sturdy stainless steel. The standard length of the tube is 500 mm, on request special lengths are also available. The outside diameter is 12 mm.

4. Assembly and Commissioning

4.1. Transport

The system and its components should be well packed and protected against shipping damage when moving the system to a new location. All the openings have to be closed during transportation in order to protect the device from dirt and grime. The device should be kept in an upright position during transport.

4.2. Intake Tube and Impactor Inlet

The device must be installed at a suitable, level installation site. The components required are the intake tube provided with a diameter of 12 mm and a length of 500 mm and the impactor inlet, which is not included in the scope of supply. To install the components mentioned, proceed as follows:

1. Remove the device and corresponding parts from the transport box and check that the contents are complete (see 1.5.).
2. Slowly and carefully place the intake tube into the intake flange of the virtual impactor from above and check to ensure that the tube is firmly seated.
3. Slowly and carefully place the impactor inlet on the upper end of the intake tube and check to ensure that the inlet is firmly seated (before starting a measurement, lubricate the impact plate of the impactor inlet).

Ensure that the upper and lower parts of the impactor inlet are firmly attached to the housing section.

4.3. External Sensor

The sensor is already screwed to a mounting bracket on delivery. To mount the sensor on the device, proceed as follows:

1. Place the entire unit (protective shield facing up) with the holes of the mounting bracket over the corresponding thread on the housing side.
2. Screw the unit firmly in place using the two knurled nuts provided.
3. Connect the cable of the sensor to the appropriate socket next to the threaded connection using the installed cable plug connector.

NOTE: If the system is used in a measurement container, the external sensor has to be mounted outside the container.

4.4. Connecting and Powering Up the System

1. Connect the power plug to the local power supply.
2. To activate the system, turn on the main power switch, located in the bottom right hand corner, and the line switch at the control unit.

After the unit has been switched on, the display will show the initialization screen for a short period of time. It will be followed by the start screen (Fig. 8). Shown in addition to the date and time of day is the model designation.

3. Read the information in the display at the control unit to determine whether the device has been correctly recognized as “APM-2”.

If the filter changer has not been identified correctly, check the cable connection and, if necessary, get in touch with Comde-Derenda GmbH.

NOTE: Whenever the system is moved to a new location observe an acclimatization period of one hour before sampling so that the external sensor can adjust to the ambient conditions.

4.5. Storage

The following instructions should be followed if the unit is moved or taken out of service for an extended period of time:

- The storage temperature should be in a range of from -10 °C to +60 °C.
- Cover the inlet for the virtual impactor.
- Protect the device’s inlets and outlets against grime.
- It is necessary to avoid both high relative humidity (which could cause condensation in case of a temperature change) and any severe vibration of the unit.

It is advisable to thoroughly clean and maintain the unit before any extended period out of service.

5. Operation and Device Settings

After the device is switched on with the main power and control unit power switches, the APM-2 main menu is shown in the display at the control unit (Fig. 8). The main menu enables access to all system settings and functions. The jog dial on the control unit (see Fig. 3) is used for navigation within the individual menus. Turn the jog dial to change from one menu item to the next and to change the parameter selected. The menu item selected at any given moment is shown inverse or outlined. Press the jog dial to confirm the selection of a menu item or to confirm a modified value.

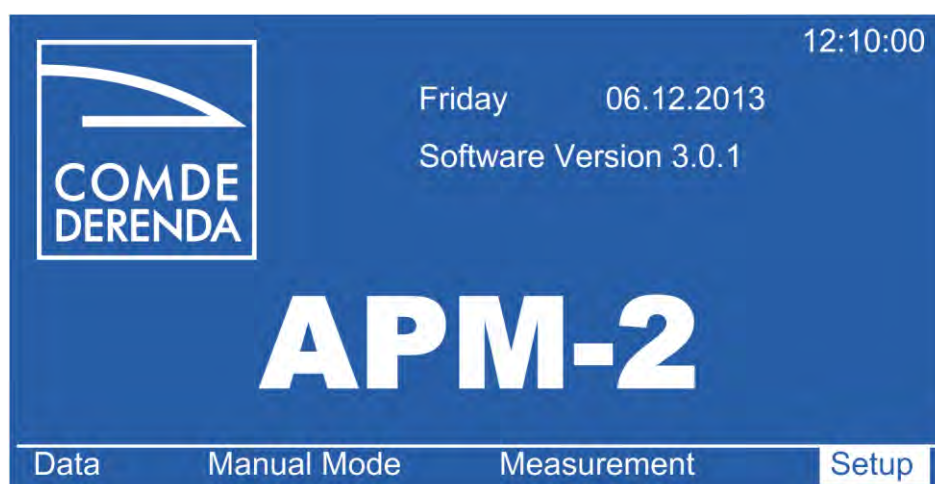


Fig. 8: Start screen with main menu

5.1. Software Design

The software makes possible convenient adaptation of all system settings and exact parameterization for the measurement being planned. See Fig. 10 for a survey of the menu structure implemented in the software. The main menu, which is always shown whenever the unit is switched on, provides access to the submenus described below.

5.1.1. Setup Menu

The **Setup** menu (Fig. 9) is used to specify numerous settings at the unit. It contains the following menu items and functions:

- **Language:** Selecting the language for the equipment software
- **Calibration:** Verifying the sensitivity of the photometer
- **Leaking Test:** Leak testing
- **Date/time:** Setting the date and time of day
- **Transfer:** Selection and configuration for data transmission
- **Contrast:** Setting the contrast level for the display screen
- **Service:** Displaying and adjusting the measured values output by the sensors

- **System info:** Information on the equipment data
- **Administrator:** Changing the password and resetting to default settings
- **Device Adjustment:** Special settings made by the manufacturer
- **Measurem. Param.:** Setting the particulate fractions to be used for measurement purposes ($PM_{2.5}$, PM_{10} or alternating mode), the target temperature for the heating block, the factors and offsets for the measurement, and the intervals for alternating mode (if selected)

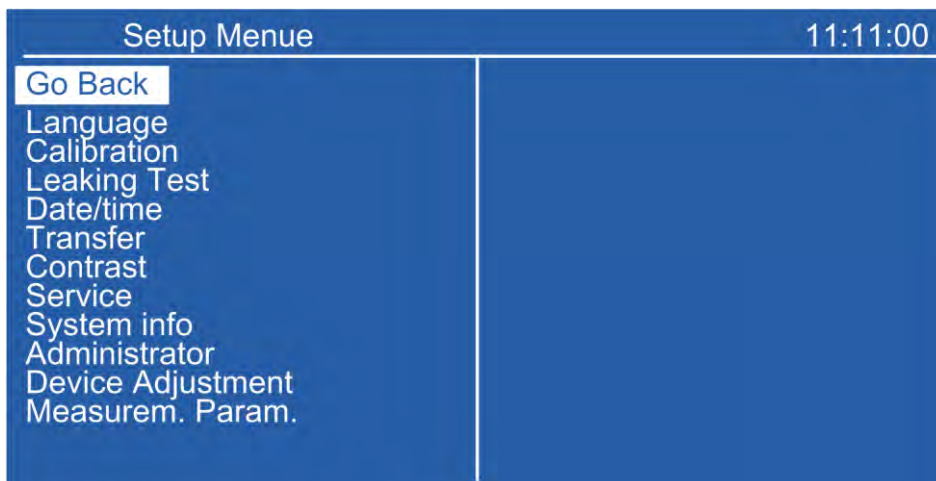


Fig. 9: Setup menu

5.1.2. Data Menu

The **Data** menu (Fig. 19) contains all the functions related to the data memory (overview, transmission and deletion of stored data) as well as a display of the capacity utilization of the internal data memory. In addition, this menu provides access to the update functions for the device software. For operation see 8.

5.1.3. Measurement

Clicking on this menu item will start the measurements and will control the volume flow correction. For operation see 6.

5.1.4. Manual Mode menu

The **Manual Mode** menu (Fig. 21) makes it possible to directly start the functions $PM_{2.5}$ measurement, PM_{10} measurement and flushing manually. The selected functions run without pauses until they are stopped by the user. This menu is primarily designed for service staff to test individual functions of the device. Normal users need it very rarely. For operation see 9.4.

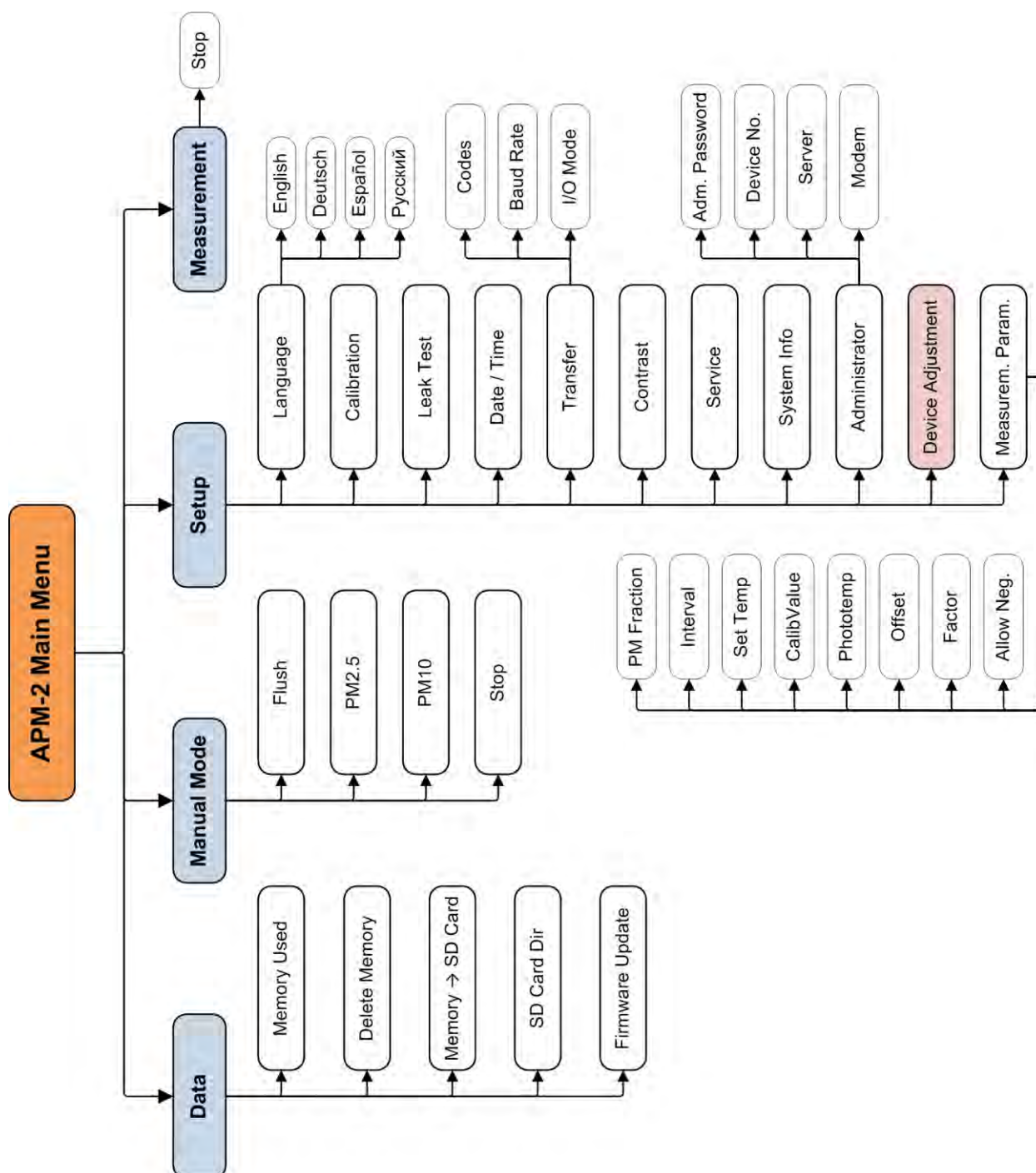


Fig. 10: APM-2 menu structure

5.2. Basic Settings

Certain basic settings will have to be made at the unit before starting the configuration work proper.

5.2.1. Choosing a Language

Follow these instructions to select the language for the operator prompts:

1. Select the **Setup** item in the main screen and confirm by pressing the jog dial.
2. When in the **Setup** menu select the **Language** item and confirm this.
3. Turn the jog dial to select the desired language displayed in the right half of the display (English, German, Spanish, Italian and Polish are available at present) and confirm your choice.
4. Confirm the **Back** menu item to return to the main menu.

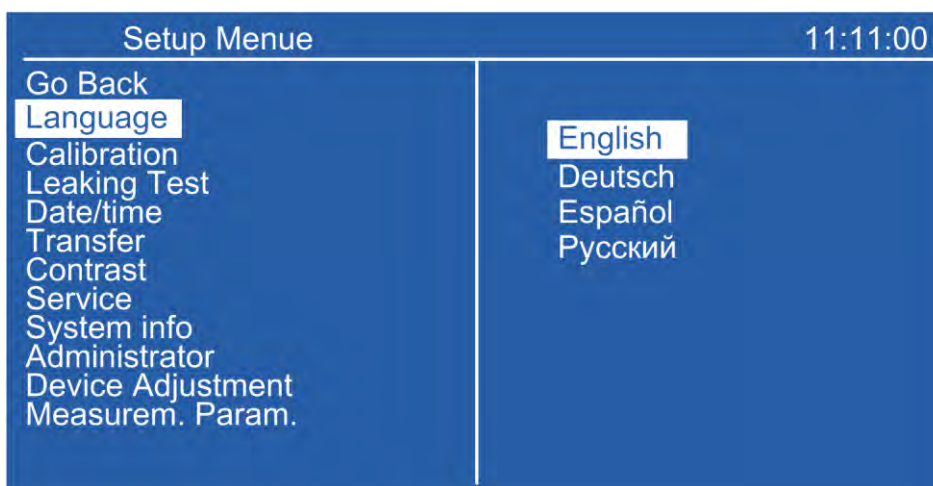


Fig. 11: Language selection

5.2.2. Setting Time of Day and Date

To set the current date and time of day:

1. Select the **Setup** item in the main screen and confirm by pressing the jog dial.
2. Select **Date/time** in the **Setup** menu and confirm.
3. Turn the jog dial in order to select the desired value (day, month, year, hour, minute, second) in the **Date/Time** screen (Fig. 12); the selected value will be outlined in each case.
4. To change the selected value press the jog dial – the value is now shown inverse – and turn the dial in the appropriate direction until the desired value is reached.
5. Press the jog dial to confirm the entry.
6. Repeat steps 3 to 5 for all the values to be changed.
7. Select and confirm **Set** to store the values shown.
8. Select and then confirm **Back** twice to return to the main menu.



Fig. 12: Setting time and date

5.2.3. Adjusting the Display's Contrast

In order to adjust the contrast in the display:

1. In the main screen select the **Setup** item and confirm this by pressing the jog dial.
2. In the **Setup** menu select **Contrast** and confirm your choice.
3. The current contrast value is shown in the right half of the display; turn the jog dial to adjust the contrast as desired, on a scale of from 0 (bright) to 63 (dark), and confirm your selection.
4. Confirm at the **Back** button to return to the main menu.

5.3. Data Transmission Settings

All the settings affecting data transmission are made in the **Transfer** menu (Fig. 14). Data transmission is effected through the RS-232 serial interface at the control unit.

5.3.1. Choosing the Input/Output Mode

You may choose from two different input/out modes for the serial interface:

1. **BH** (Bayern-Hessen-Protokoll / Bavaria-Hesse protocol): All measured values with a measured value identifier not equal to "000" will, upon request, be transmitted as per the Bavaria/Hesse protocol. The measured value transmission sequence is sorted in accordance with the measured value identifiers (see 5.3.2).
2. **Serial** (serial mode): All eight of the recorded measured values (see 5.3.2) and the following additional information will be forwarded via the RS-232 interface to a PC equipped with a terminal emulation program: date; time of day; device type and serial number; event; error (using semi-colon as the separator).

Specify the I/O mode as follows:

1. In the main screen, select **Setup** and press the jog dial to confirm.
2. In the **Setup** menu, select **Transfer** and confirm your choice.
3. In the **Transfer** menu (Fig. 14) turn the jog dial until the desired mode (BH or Serial) is shown in-verse.
4. Press the jog dial to confirm your mode selection.
5. Select **Set** and confirm to save your settings.

Date	Time	Type	S/N	Flush (mV)	PM2.5 (ug/m3)	PM10 (ug/m3)	Motor-speed (%)	Photometer Temp. (°C)	POutside (hPa)	TOutside (°C)	rel. Humidity (%)	Event	Error
08.11.2013	12:02:22	APM-2	0	3081	0	0	0	43,8	1010,4	20	50	Start	ext. Sensor
08.11.2013	12:02:26	APM-2	0	3039	0	0	100	43,7	1010,7	20	50	Stop	ext. Sensor
08.11.2013	12:33:27	APM-2	0	0	0	0	0	40	1010,9	20	50	Start	ext. Sensor
08.11.2013	12:35:00	APM-2	0	3005	0	0	100	40,1	1010,4	20	50	PFlush	ext. Sensor
08.11.2013	12:36:00	APM-2	0	3001	0	0	100	40	1010,9	20	50	Flush	ext. Sensor
08.11.2013	12:38:00	APM-2	0	3001	28	0	67	40,1	1010,7	20	50	PM2.5	ext. Sensor

Fig. 13: Example for the way the measured data are output in serial mode at the interface (corresponds to the log file on the SD card)

5.3.2. Setting Identifier Codes for Individual Parameters

The following 8 measurement parameters can be transferred by the system:

1. **Air Flush mV** (voltage at photometer during zero air flushing)
2. **Concent. PM2.5 $\mu\text{g}/\text{m}^3$** (PM_{2.5}-concentration in $\mu\text{g}/\text{m}^3$)
3. **Concent. PM10 $\mu\text{g}/\text{m}^3$** (PM₁₀-concentration in $\mu\text{g}/\text{m}^3$)
4. **Ambient temperature** (temperature of the outside air)
5. **Relative humidity** (humidity of the outside air)
6. **Ambient pressure** (pressure of the outside air)
7. **Photo. temperature** (temperature of the photometer)
8. **Error** (warning message, if temperature and/or volume flow is outside of the tolerance range)

Individual identifier codes can be assigned to each of these parameters in preparation for data transmission in accordance with the Bavaria-Hesse protocol. The code for each parameter comprises three digits. To set the individual codes:

1. When in the **Transfer** menu, turn the jog dial until the numerical code next to the desired parameter (e.g. **Air Flush mV**) is shown outlined in the display, and confirm by pressing the jog dial.
2. Turn the dial to change the code, and press it again once the desired value has been reached.
3. Repeat steps 1 and 2 for all the other parameters.
4. Go to **Set** and press the jog dial to store the modified codes.
5. Go to **Back** and press the jog dial to leave the **Transfer** menu.

NOTE: Parameters with code “000” will not be transmitted in **BH** (Bavaria-Hesse protocol) mode. In **Serial** mode, all 8 parameters are generally transmitted.

Parameter ID (BH)	12.12.2013	11:11:00
Air Flush mV	201	
Concent. PM2.5 ug/m3	202	
Concent. PM10 ug/m3	203	
Ambient temperature	204	
Relative humidity	205	
Ambient pressure	206	
Photo. Temperature	207	
Error	208	
Baudrate	4800	
Serial I/O Mode	BH	serial
	Set	Back

Fig. 14: Tranfer menu

5.3.3. Setting the Baud Rate

The baud rate used for data transmission can be set optionally for 1200, 2400, 4800 or 9600. Make this setting as follows:

1. When in the **Transmission** menu select **Baudrate** and confirm your choice.
2. Turn the jog dial to change the value (displayed inverse) for the baud rate; press the jog dial to confirm the new value.

5.4. Administrator Settings

In order to access the **Administrator** settings it is necessary first to select **Administrator** in the **Setup** menu and then to enter the administrator password, digit by digit, and to confirm the entry by selecting **OK** and pressing on the jog dial (Fig. 15). Then you can make the settings described below in the administrator menu (Fig. 16). The password set at the factory is “0000”.

5.4.1. Editing the Device Number

In addition to the serial number assigned by the manufacturer, you may assign a five-digit device number to the instrument. To set or edit the device number:

1. In the **Setup** menu, select **Administrator**, enter your password as described above and go to the **Device Number** line.
2. Click on the left-hand digit and change it by turning the jog dial; apply and confirm the change by pressing the jog dial.
3. Edit the other four digits as described in step 2, above.

The device will then automatically store the change. The new device number will be used when using the Bavaria-Hesse protocol.

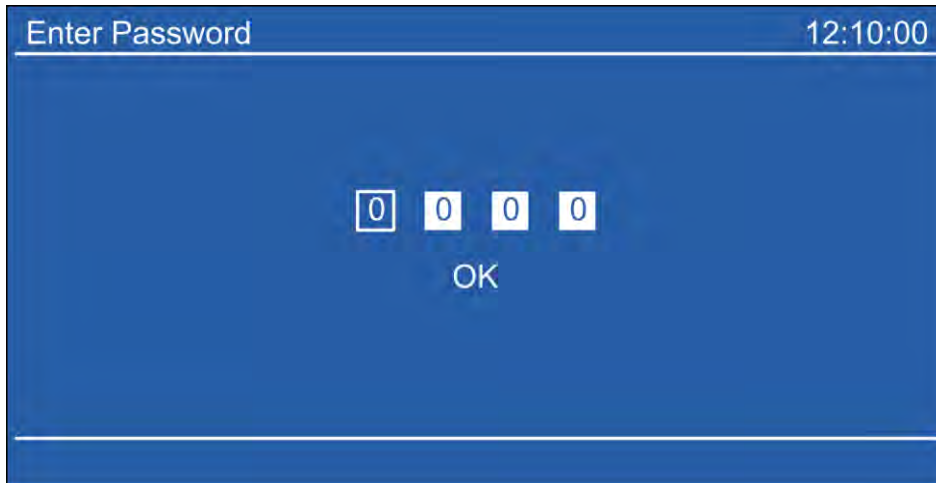


Fig. 15: Password screen

5.4.2. Changing the Administrator Password

Change the four-digit administrator password as follows:

1. When in the **Administrator** menu go to the line **Admin-Password**.
2. Click on the left-hand digit, turn the jog dial to change it, and confirm the change by pressing on the jog dial.
3. Proceed for the other three digits as described in step 2.



Fig. 16: Administrator menu

5.4.3. Server Settings

In preparation for transmitting the data measured by the APM-2 to a web server via the GSM/GPRS module (available as an option), it is necessary for an authorized web administrator to first install the corresponding software package to the target server. If you have any questions about this, please get in touch with Comde-Derenda. Then, in the **Administrator** menu, enter the server's domain and subdomain names. Do so as described below:

1. Store on an SD card a text (.txt) file, containing as text the designation of the domain / subdomain (e.g. "apm2.derenda.de"). The file must be named: *server.txt*.
2. Mount the card in the SD card drive at the APM-2 control unit.
3. In the **Administrator** menu, click on **Server**.
4. Answer the query which follows with "Yes".

The name of the server will then appear in the **Administrator** menu (see Fig. 16).

5.4.4. Selecting the Modem Type

To select an internal or external modem for data transmission:

1. In the **Administrator** menu, go to the **Modem** line.
2. Turn the jog dial to select either **internal** or **external**, and confirm by pressing the jog dial.

5.5. Device Adjustment Menu

The **Device Adjustment** menu enables authorized service technicians to make changes to specific system settings. This menu is protected by a special password.

6. Parameterizing and Starting a Measurement

After you have carried out the system settings described under 5.2 to 5.4, you can then parameterize and activate the planned measurement. After selecting the desired particulate matter fraction (PM_{2.5}, PM₁₀ or alternating mode) and, if applicable, the desired interval for alternating mode and the set temperature of the heating block, you can start the measurement. Various data on the measurement are shown in the display during operation.

APM Parameter		12.12.2013	12:20:00
PM2.5	PM10	PM2.5/10	Offset2.5: 1.00
Save file:			Factor2.5: 0.00
2	5	10	Offset 10: 1.00
		15	Factor 10: 0.00
		min	Allow Neg.: 0
Set Temp:	40.0°C		
CalibValue:	90.0		
Phototemp:	39.0°C		
Back			

Fig. 17: Measurement parameters in the *APM parameter* menu

In order to access the measurement parameter settings it is necessary first to select **Measurem.Param.** in the **Setup** menu and then to enter the password, digit by digit, and to confirm the entry by selecting **OK** and pressing on the jog dial (Fig. 15). Then you can make the settings described below in the APM Parameter menu (Fig. 17). The password set at the factory is "0000".

6.1. Selecting Particulate Matter Fraction

First of all, you select the particulate matter fraction to be measured. Here you have a choice between PM_{2.5}, PM₁₀ and alternating measurement of both fractions (alternating mode). To select the fraction to be measured:

1. In the **Setup** menu, select **Measurem.Param.** and enter your password as described above.
2. In the **APM parameter** menu (Fig. 17), select the desired fraction (**2.5**, **10** or **2.5/10** for alternating mode) in the top left entry line by turning the jog dial to shift the inversion, and press the jog dial to confirm.

After that, the selected value appears outlined and the selection remains active until it is changed.

6.2. Selecting Interval for Alternating Mode and Storage

If you have selected alternating mode 2.5/10 as the measurement mode, the APM-2 alternately measures the concentration of the particulate matter fractions $PM_{2.5}$ and PM_{10} . The device automatically carries out the necessary zero air flushing for a period of two minutes on an hourly basis. Using the interval setting, you can specify the intervals at which the change between the two fractions should take place. In addition, this setting specifies at what intervals the measurement data are stored in the internal device memory and/or – if provided – on the SD card. To carry out the setting:

1. In the **Setup** menu, select **Measurem.Param.** and enter your password as described above.
2. In the **APM parameter** menu, select the desired interval (2, 5, 10 or 15 minutes) in the entry line under **Save file** by turning the jog dial to shift the inversion and pressing the jog dial to confirm.

The selected value then appears outlined and the selection remains active until it is changed.

6.3. Selecting the Set Temperature for the Photometer

The photometer unit has to be heated in order to rule out measurement errors (see 3.1.4). In normal cases the target temperature should be set to 40°C because this setting has proven to be appropriate in practice. To modify the value:

1. In the **Setup** menu, select **Measurem.Param.** and enter your password as described above.
2. In the **APM parameter** menu, turn the jog dial until the value to the right of **Set temp.** is outlined, and press the jog dial.
3. Turn the jog dial to change the value.
4. Press the jog dial again to save the changed value.

The selected value remains active until it is changed.

NOTE: The parameterization options in the APM parameter menu regarding volume flow calibration as well as the factor and offset settings are described in sections 9.5. and 9.8.

6.4. Starting the Measurement

After completing parameterization, start the measurement by calling up the APM-2 main menu; select the **Measurement** menu item and confirm by pressing on the jog dial. Measurement will commence immediately. After it has started, you will see the **APM Measurement** menu (Fig. 18) in the display.

7. Measurement Procedure

The measurement will not start until the photometer has reached its target temperature. When the measurement starts, first the pump runs up and all device components are activated. The selected measurement program begins after that.

7.1. Flushing with Zero Air

First the photometer unit is flushed with air that has previously flowed through a zero air filter for a period of two minutes. This is necessary for zero point adjustment of the photometer. This zero air flushing is carried out automatically by the device for two minutes in each case at hourly intervals, also in the further course of the measurement. During flushing, the word “**Flush**” will be displayed on the right-hand side of the display.

7.2. Start of the Measurement and the Measurement Menu

The actual measurement starts immediately after the first flushing. You see the **APM Measurement** menu in the display. In addition to date and time, it indicates on the right side the currently measured mass concentration of the selected particulate matter fraction in $\mu\text{g}/\text{m}^3$ or, during a flushing operation, the measured voltage value in mV. On the left side of the screen the following values are shown in the two window sections **Measured Values** and **Physical Data**:

- **PM 2.5 avg**: Mean value of the measured mass concentration for $\text{PM}_{2.5}$ (if active)
- **PM 10 avg**: Mean value of the measured mass concentration for PM_{10} (if active)
- **Fl. Offset**: Photometer offset, determined during zero air flushing
- **Phototemp**: Temperature at photometer
- **Ext. Temp**: Temperature determined by external sensor
- **Humidity**: Humidity determined by external sensor
- **Pressure**: Air pressure determined by external sensor

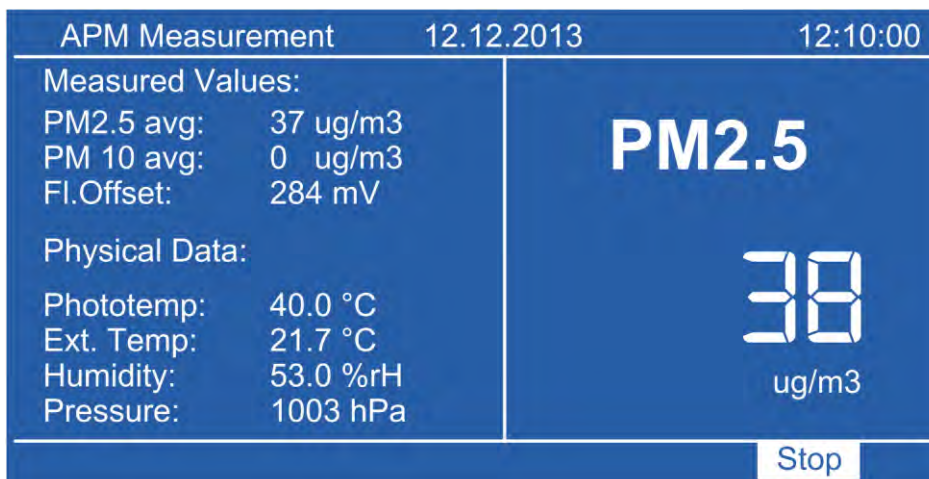


Fig. 18: APM Measurement menu

7.3. Aborting the Measurement

To abort an ongoing measurement, select the menu item **Stop** in the **APM Measurement** menu and press the jog dial to confirm. The measurement is then stopped and the main menu screen is displayed.

8. Data Management

The **Data** menu (Fig. 19) serves to manage the measurement data in internal storage and/or on the SD memory card. You access this menu via the **Data** menu item in the main screen.

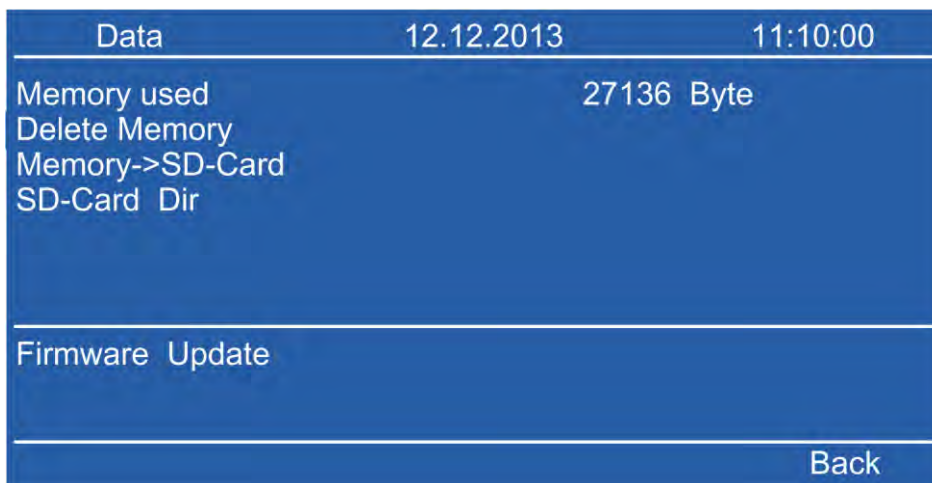


Fig. 19: Data menu

Shown at the right in the screen is the memory usage in bytes. The total free capacity of the data memory is 3.5 MB. The following data and parameters for sampling are automatically stored in the unit's memory, individually for each sampling filter:

- **Date, starting time and duration of measurement**
- **Unit model and serial number**
- **Mean mass concentration of the measured particulate matter fraction in $\mu\text{g}/\text{m}^3$**
- **% of the maximum pump motor speed**
- **Outside air pressure**
- **Outside air temperature**
- **Photometer temperature**
- **Relative humidity**
- **Any reportable events and errors**

A data record that comprises the information listed above will require 128 bytes. As a consequence, about 27,000 data records can be placed in storage. The system uses a non-volatile ring memory. The data are retained even if the device is switched off. Once the memory is full, the oldest data is overwritten with the new data. Since overwriting works reliably only for a limited number of cycles, the memory should be erased at regular intervals.

If an SD memory card is present in the device, then the data will also be automatically written as a text file (CSV file format) on the SD memory card.

8.1. Storing Data on an SD Memory Card Manually

In addition to ongoing automatic storage, all the data can also be transferred manually from the device memory to an SD memory card. Transfer is in the serial mode, corresponding to normal data output (see 5.3.2). To start data transfer to an SD card, select and confirm menu item **Memory → SD Card** in the **Data** menu. This function is useful if, for instance, no SD memory card had been mounted in the device during measurement operations.

8.2. Erasing Data Memory

It is recommended that the device memory be erased at regular intervals, e.g. whenever the SD card is replaced. To do so, select and confirm the **Erase memory** menu item in the **Data** menu and affirm the following confirmation prompt.

8.3. Displaying Data Content of an SD Memory Card

Use the **SD card dir** command in the **Data** menu to display the data stored on the SD memory card. The .csv files present on the SD card, containing the data for the measurement, can be opened with any PC and can be viewed and edited with a suitable program such as Microsoft Excel®.

NOTE: See 9.1 for information on updating the firmware.

9. Special Functions

Described below are some of the device's functions that are irrelevant to normal operations but which nonetheless may occasionally be required.

9.1. Updating the Firmware

It may occasionally be necessary to update the equipment's operating program. An SD memory card with the software to be installed is required for this purpose. Please apply to Comde-Derenda GmbH to receive the latest version.

CAUTION! Pay attention to compatibility issues: If the parameter records in the old and new versions of the firmware are not identical, then settings may be lost and the proper functioning of the device may be endangered. Please contact Comde-Derenda GmbH prior to updating in order to clarify compatibility questions.

Proceed as follows to update the firmware:

1. Mount the SD memory card with the update file in the SD card slot at the upper right hand corner of the control unit.
2. In the main menu, select the **Data** menu item and confirm by pressing the jog dial.
3. In the **Data** menu, select the **Firmware Update** item and confirm your choice.
4. Confirm with **Yes** the query as to whether you want to proceed with the update.

The update will now be installed. A bar appears, showing the progress of the copying procedure. Once the update has run successfully to completion, the display will show **OK**. The unit will then automatically be reset and restarted.

WARNING! The unit must not be switched off while the software is being upgraded. This would cause data loss, the device could no longer be used and it would have to be returned to the factory for repairs before it could be returned to service.

9.2. System Information

Proceed as follows to call up the system information:

1. Select the **Setup** menu item in the main screen and confirm your choice by pressing the jog dial.
2. When in the **Setup** menu select the **System info** item and confirm your choice.

You will see the following information in the **System information** screen:

- **Software-Vers.:** Software release version number
- **Hardware-Vers.:** Hardware version number
- **Series Number:** Device serial number

- **Device Number:** Device number assigned by the user (see 5.4.1)
- **Last Flow Calib.:** Date and time of the most recent calibration of the flow sensor
- **Last Photo Calib.:** Date and time of the most recent service for the photometer
- **Model Number:** GPRS modem type
- **Firmware Rev:** Firmware version for the GPRS modem
- **Network Stat.:** Status of the GSM/GPRS connection
- **IP Address:** IP address of the GPRS connection

See section 9.5.3 for details on calibrating the flow sensor.

System Information		12:10:00
Software Vers. :	3.0.1	
Hardware Vers. :	5.2A	
Serial Number :	00078	
Device Number :	00004	
Last Flow-Calib. :	23.10.2013	12:37:55
Last Photo-Calib.:	16.09.2013	18:26:49
Model Number :	GE864-QUAD	
Firmware Rev. :	10.00.014	
Network Stat. :	registered	
IP Address :	88.128.226.63	
		Go back

Fig. 20: System Information screen

9.3. Service Menu

The **Service** menu is used primarily to check the sensors and for adjustment and maintenance work carried out by service technicians. This menu will not usually be used in normal operations. You access the **Service** menu from the main screen by selecting **Setup** → **Service**.

Shown in the **Service** menu are all measured values reported by the unit's sensors together with the corresponding correction parameters.

9.4. Manual Mode

The **Manual Mode** menu allows you to start individual system functions manually. It is primarily designed for service technicians who want to test individual functions. Manual mode is not suitable for regular measurements of the particulate matter mass concentration because there is no automatic flushing during the measurement. You can call up the following functions via the **Manual Mode** menu:

9.4.1. Flushing

Carry out manual activation of zero air flushing of the photometer unit as follows:

1. Select the **Manual Mode** menu in the main menu and press the jog dial to confirm.
2. Select the item **Flush** in the **Manual Mode** menu and confirm.

Flushing starts immediately. During flushing you see the current value of the voltage signal at the photometer on the right side of the display, and left of that the offset voltage value of the photometer determined during flushing. To stop flushing, select and confirm the menu item **Stop**.

9.4.2. Measuring PM_{2.5} oder PM₁₀

Start a manually activated measurement of PM_{2.5} or PM₁₀ particulate matter as follows:

1. Select the **Manual Mode** menu in the main menu and press the jog dial to confirm.
2. Select the item **PM2.5** or **PM10** in the **Manual Mode** menu and confirm.

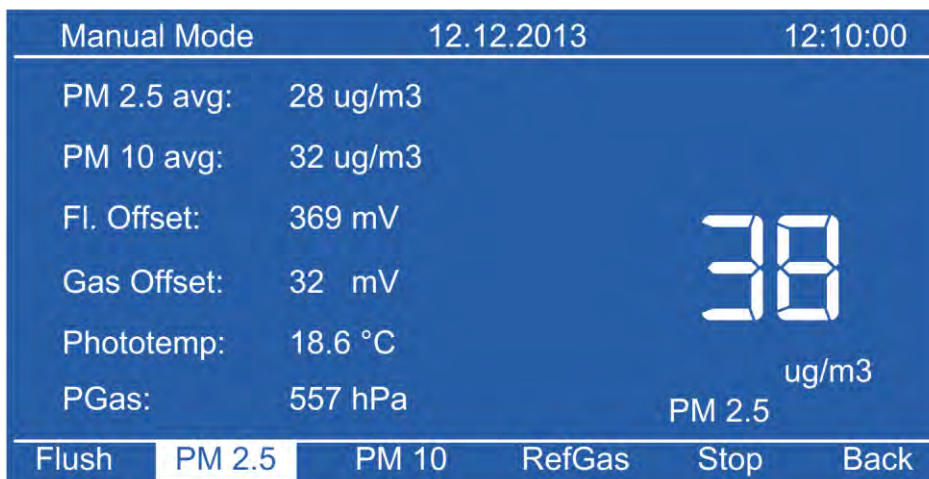


Fig. 21: Manual Mode menu

The measurement starts immediately. The current value of the mass concentration is shown on the right side of the display during the measurement. On the left you see the corresponding mean value for the measurement, which is updated once every second. To stop the measurement, select and confirm the menu item **Stop**.

9.5. Calibrating the Flow Sensor

For correct measurement operation, the volume flow of the drawn-in air has to be 3.3 l/min during the measurement. When in continuous operation, the flow sensor shall be calibrated once a month. Calibration will require an external flow meter, which is not included in the standard scope of delivery.

9.5.1. Preparing for the Calibration

Prior to calibration of the flow sensor the APM-2 should be run for a period of 15 minutes so it warms up. For this purpose, parameterize and start a measurement. Additionally check the values for outside air temperature (**Ext. Temp**) and air pressure (**Pressure**) indicated on the left side of the **APM Measurement** menu (Fig. 18). If they should deviate from the values of calibrated reference instruments by more than 2 K and 4 mbar respectively, temperature and/or pressure sensors first have to be calibrated/adjusted, see 9.3.

9.5.2. Connecting the external flow meter

1. Remove the impactor inlet by pulling it off the intake tube in an upward direction.
2. Shift the calibration adapter to the upper end of the intake tube and ensure that the adapter is firmly seated.
3. Connect the calibration adapter and the external flow meter using the corresponding hose.

APM Parameter			12.12.2013	12:20:00
PM2.5	PM10	PM2.5/10	Offset2.5	1.00
Save file:			Factor2.5:	0.00
2	5	10	15	min
Set Temp.:	40.0°C		Offset 10:	1.00
CalibValue:	92.6		Factor 10:	0.00
Phototemp:	39.0°C		Allow Neg.:	0
Back				

Fig. 22: Adjusting the pump's power setting

9.5.3. Calibrating the Flow Sensor

The calibration process is controlled via the control unit:

1. Select the **Setup** menu in the main menu and press the jog dial to confirm.
2. In the **Setup** menu, select the **Measurement parameter** item and confirm your choice.
3. In the **APM Parameter** menu, select the value shown to the right of **CalibValue** so that it is shown outlined and press the jog dial. The value is now shown inverse (Fig. 22).

4. Observe the display of the external flow meter and, if necessary, adjust the pump motor speed by turning the jog dial until the value indicated by the flow meter corresponds exactly to 3.3 l/min. The volume flow correction value also changes accordingly.
5. After the correct value is reached, press the jog dial.
6. To go back to the main menu, select and confirm **back**.

9.5.4. Checking the Accuracy of the Calibration

After completion of the calibration procedure start a measurement as a test. Please wait until the device automatically changes into the PM_{2.5} or PM₁₀ measurement mode. Check the display of the external flow meter for agreement with the set value. In the event of deviations, repeat the calibration as described.

9.6. Inspecting the Photometer

In addition to calibrating the photometer at regular intervals (see 10.3), it is also possible to use a test gas to verify its functioning and sensitivity. You will need optional devices and documentation to carry out the inspection with the test gas. These can be obtained on request from Comde-Derenda GmbH.

9.7. Leak Tightness Test

An automatic leak tightness test is provided in the APM-2 to check the tightness of the system; this is started via the device firmware. This test requires the Comde-Derenda leak test instrument (Fig. 24), available separately.

9.7.1. Sequence for Leak Tightness Testing

Leak testing is started by using the internal pump to create a vacuum of approx. 300 hPa inside the device. Then observe the system to determine whether and the extent to which this pressure rises within the following 5 minutes. The test is considered to have been passed if the pressure rise is less than 290 hPa. Otherwise the system is leaking and will have to be inspected.

The test at the zero air port is optional and intended primarily for use by service technicians.

9.7.2. Leaking Test Menu

The leak test is conducted using the APM-2 control unit. The appropriate menu is called up by selecting **Setup** → **Leaking Test**.

Shown in the center of the menu window is the name of the function currently being run and the appropriate progress bar. The following values are shown in the lower section of the window:

- **PGas:** Current vacuum in the system, in hPa
- **Zero air:** Starts the leak test when the leak testing instrument is connected to the zero air port
- **Inlet:** Starts the leak test when the leak testing instrument is connected to the virtual impactor
- **Stop:** Terminates a leak test currently being conducted
- **Back:** Leaves the **Leaking Test** menu

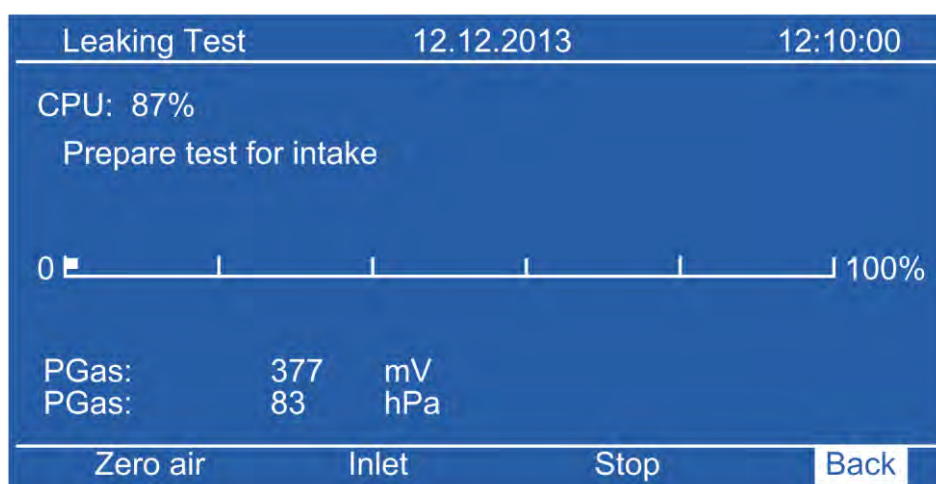


Fig. 23: Leaking Test menu

9.7.3. Conducting the Leak Tightness Test

Follow the instructions below to conduct a leak test.

1. Ensure that the APM-2 is switched off.
2. Remove the impactor head from the APM-2 by pulling it upward and off of the inlet tube above the virtual impactor.

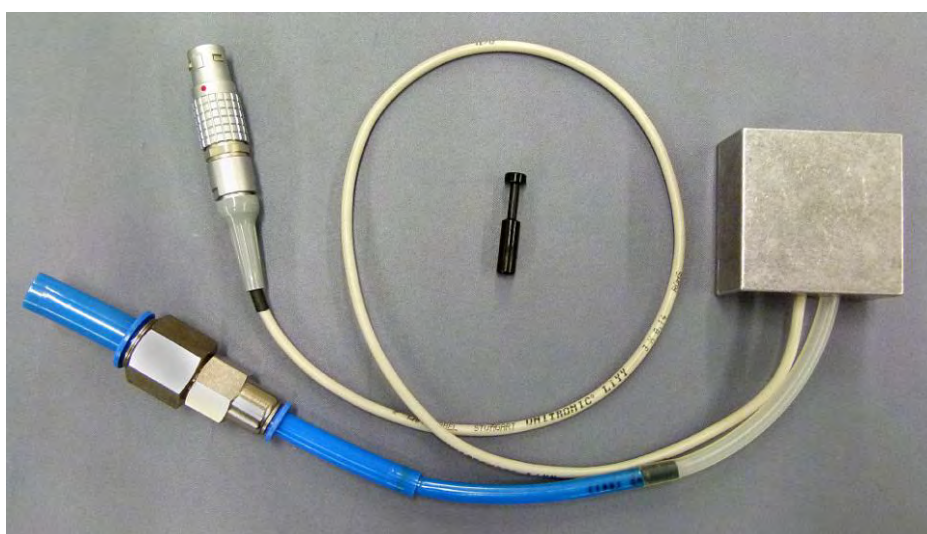


Fig. 24: Leak testing instrument

3. Lift the inlet tube off the virtual impactor.
4. Connect the leak testing instrument (Fig. 24) with the control cable socket on the APM-2. The 7-pole socket is located on the front panel of the APM-2 control unit.
5. Power up the APM-2 by turning on the main switch on the front panel and the switch on the front of the control unit.
6. Disconnect the coarse filter (with tube) from the zero air port on the left-hand side of the unit.
7. Insert the closure plug into the socket at the zero air port.
8. Join the leak testing instrument with the APM-2 by inserting the hose fitting into the virtual impactor inlet port (Fig. 25).

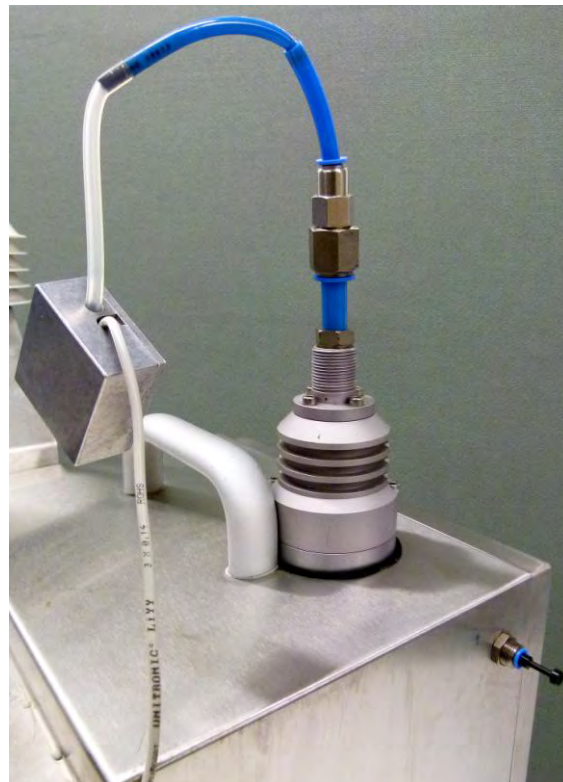


Fig. 25: Connecting the leak testing instrument

9. At the APM-2 control unit, call up the **Leaking Test** menu with menu items **Setup** → **Leaking Test**.
10. Click on menu item **Inlet** to start the automatic testing process.

NOTE: If there is any vacuum in the device at the beginning of the test, then the testing cycle cannot be started. The appropriate message will appear in the display, requesting that the device first be vented. To do so, briefly detach the fitting on the gas hose from the adaptor at the virtual impactor and then reconnect the hose. To begin the test cycle, select and confirm the **Start** menu item. The leak test is not available in all versions of the device.

The steps in the testing process follow this sequence:

1. **Generating a vacuum:** The message “**Leak test starting**” will appear briefly in the display. The internal pump will generate a vacuum in the APM-2 to a pressure level of approx. 300 hPa.
2. **Testing phase:** The testing phase will commence once the vacuum has been generated. During this period, the vacuum in the system will be monitored continuously by the sensors in the device and shown as the **PGas** value in the display.

3. **Displaying the results:** A tolerance of 290 hPa applies to the rise in pressure. If the pressure during the test phase remains the same or has risen by no more than 290 hPa, then the test is deemed to have been passed. If the pressure has risen by more than 290 hPa, then the test has been failed. The results will be shown accordingly in the display. This concludes the leak test.

To leave the menu after the test, select the **Finished** menu item and respond to the following confirmation question with **Yes**. While the test is running, the sequence may be aborted by selecting the **Stop** menu item; it may be recommenced with **Start**. If the test is not successful, first attempt to locate and correct the reason for the leak (e.g. a hose that is connected loosely). If this cannot be done, then the device will have to be inspected at the factory. In this case please contact Comde-Derenda GmbH.

9.8. Factor and Offset Settings

In the device the values determined during a measurement are in the form of voltage in mV. The measured value is then converted to $\mu\text{g}/\text{m}^3$ by means of correction factors (multiplication). Depending on the measurement situation, it may be necessary to adjust these factors for $\text{PM}_{2.5}$ and PM_{10} separately in each case. For this purpose the measurement results are compared to those of a reference device in a measurement series and on this basis the necessary correction factors are calculated mathematically. The values determined by the device regarding offset values can also be adjusted, again separately for $\text{PM}_{2.5}$ and PM_{10} . To enter the factor and offset settings, proceed as follows:

1. Select the **Setup** menu in the main menu and press the jog dial to confirm.
2. In the **Setup** menu, select the **Measurement parameter** item and confirm your choice.
3. Select the value next to the desired variable (**Factor 2.5**, **Factor 10**, **Offset 2.5** or **Offset 10**) in the right-hand section of the menu so that this value is shown outlined and press the jog dial. The value is now shown inverse.
4. Adjust the value according to the previously calculated values by turning the jog dial and press the jog dial to confirm. The change is thus saved.

9.9. Allowing Negative Measured Values

This function is relevant only for service technicians and is not required in standard operation. The value should, in the normal case, be left at "0". Change the setting for negative measured values as follows: The change is thus stored.

1. Select the **Setup** menu in the main menu and press the jog dial to confirm.
2. In the **Setup** menu, select the **Measurement parameter** item and confirm your choice.
3. Click on the value displayed next to **Allow Neg.** and modify as desired (**0** = negative values not permitted, **1** = negative values permitted).

4. Press the jog dial to confirm. The change is thus saved.

10. Service and Maintenance

10.1. General

The device requires little service. The photometer chamber is cleaned automatically by the device during the measurement operation and should not be opened.

10.2. Internal Filters

The replacement intervals for the filters vary widely, depending on the level of air pollution. In general, the filters should be replaced after six months, at the latest. For the zero air filter, the change in the photometer offset value may be used as an indicator of the loading level. Minor fluctuations in the offset (by a few tens of a mV) are normal. If the offset should, however, rise by several hundred mV, then this is evidence of a clogged or damaged zero air filter. The condition of the filter shall be inspected at regular intervals.

To change the internal filters, switch off the device and disconnect it from the power supply.

The existing filters:

- 1 zero air filter (type Parker Balston)
- 1 photometer outlet filter (type Parker Balston)
- 1 bypass filter (type WIX)
- 1 pump outlet filter (type WIX)

can simply be pulled off the silicone hoses and replaced (see 10.7).

10.3. Photometer Unit

The photometer in the APM-2 shall be calibrated once a year. Do this by sending the photometer in its casing to Comde-Derenda GmbH and by contacting our customer service department.

It will be necessary to replace the photometer after a certain period in service. The photometer is to be changed if either of the following criteria is fulfilled:

- If the total amount of particulate matter collected exceeds 50 mg. This corresponds to a throughput of about $100 \mu\text{g}/\text{m}^3$, continuously over 100 days, or $50 \mu\text{g}/\text{m}^3$, continuously over 200 days, or $10 \mu\text{g}/\text{m}^3$, continuously over 1,000 days.
- If the photometer offset value has risen to more than 2,500 mV.

If one of these events occurs, then please contact Comde-Derenda GmbH. The replacement of the photometer, which may then be necessary, will be carried out by Comde-Derenda GmbH.

10.4. Vacuum Pump

The vacuum pump is powered by a brushless motor and requires no maintenance. The normal service life of the pump, when in continuous operation, is about two years. This period of time may vary, depending on the use. The pump will have to be replaced once it has reached the end of its service life. Should the pump fail, the device will automatically issue the appropriate warning.

10.5. Impactor Inlet

The impactor inlet should be cleaned according to the specific load, but every 28 days at the latest. To do so, pull the inlet off the intake tube and open it. The lubricated baffle plate and the impactor section are inside. The baffle plate can be cleaned with spirit and then recoated with Vaseline or high-vacuum grease (medium). The use of high-vacuum grease (medium) is especially recommended at low ambient temperatures.

You can either blow out the impactor section with compressed air or clean it in an ultrasonic bath.

10.6. Virtual Impactor

The virtual impactor shall be cleaned after 90 days at the latest, with the exact value depending on the amount of loading. For cleaning purposes you need to take off the connecting hoses to the virtual impactor inside the device. Then you can blow out the virtual impactor with compressed air. Once a year you should clean the virtual impactor with spirit or highly volatile alcohol to remove deposits.

10.7. Spare Parts

Item	Type	Part Number
Zero Air Filter	Parker Balston	D100010
Photometer Outlet Filter	Parker Balston	D100010
Bypass Filter	WIX	D100020
Pump Outlet Filter	WIX	D100020
Brushless Pump	Nitto Kohki	D100093
Pinch Valve	Sirai	D100833
Silicon Hose	Espass	D100823

11. Error Messages

Warnings or error messages may be issued from time to time during operation. Details on the individual reports will be found in the following table. Even after a fault message has been issued, the device will continue to function without any interruption. After a power outage, the device will automatically restart measurement operations. The measured data recorded up until the power outage occurred will be retained in memory.

Error	Description
Error_EXTSENSOR	Warning: External temperature/moisture sensor not connected or faulty
Error_POWERLOSS	Warning following power outage; measurement was restarted after power restored
Error_ENDOFLOG	Warning: Overrun at internal log memory; SD card can no longer store all the malfunctions
Error_RAMCLOCKOVERFLOW	Warning: Overrun at internal log memory (only after restarting, if the internal memory is still in an overflow state)
Error_PUMPNOFLOW	Malfunction: Pump creating no measurable flow Check pump: Seized or defective?
Error_NOPHOTOMETER	Malfunction: Photometer values below limit value Check photometer: Is it connected?
Error_HEATINGPHOTO	Malfunction: Photometer chamber not connected correctly Check: Temperature sensor at photometer defective?
Error_PARAMETERCRC	Malfunction: Can appear following a firmware update; be absolutely sure to load the factory defaults and calibrate the device Before updating the firmware, be absolutely sure to copy down the old parameters shown in the menu!
Error_MENUITEM	Please notify the manufacturer

12. Bayern-Hessen-Protokoll (Bavaria-Hesse-Protocol)

12.1. Interface Definition “Serial Measuring Instruments”

Being used ever more frequently in pollution measurement networks are intelligent, microprocessor-controlled measurement units fitted as standard equipment with an interface to transfer measurement data, operational status information and error status.

To ensure trouble-free attachment of a wide variety of equipment, a standard interface is described below, similar to the “50-pole data plug” described in the “Standardization Recommendation for Automated Air Quality Control Measurement Networks”.

12.2. Interface Specification

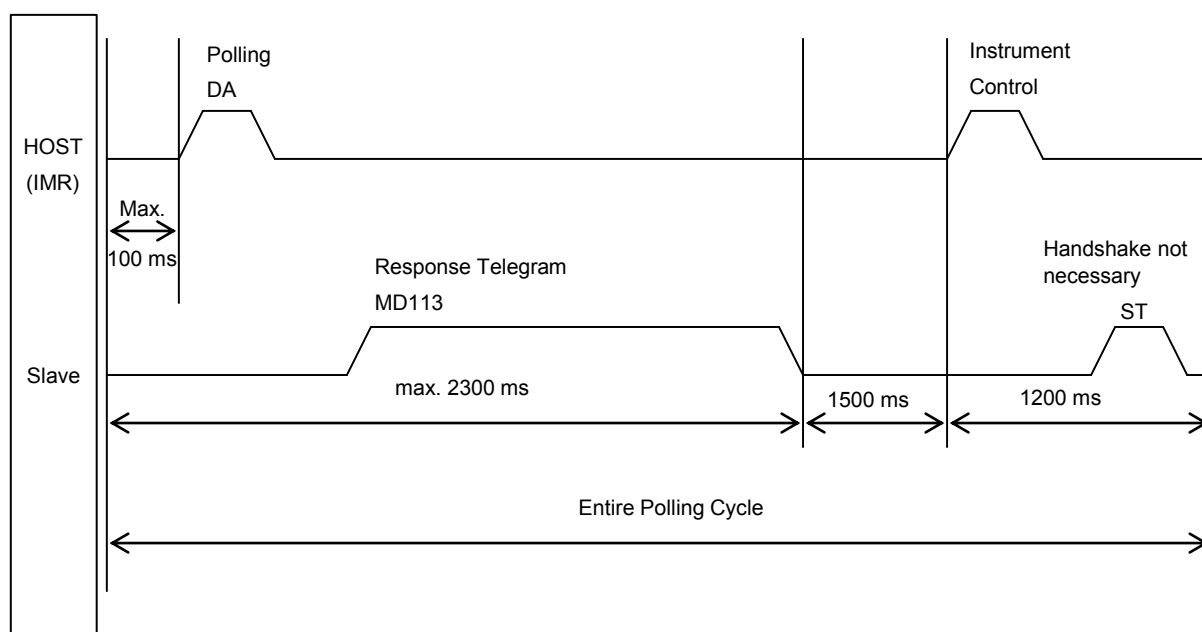
Asynchronous-serial Data Transfer

Baud Rate:	1200 Baud
Data Format:	1 Start Bit
	8 Data Bits
	1 Stop Bit
Handshake:	Full-duplex Operation; Polling Method (MSR = Master)
Connector:	9-pole SUB-D-Connector with the PIN configuration: PIN 02: TxD Send Data (Off) PIN 03: RxD Receive Data (On) PIN 05: GNDGround
Voltage Level:	According to norm V24; not potential-free For Data Lines (RxD, TxD): -15 to – 3V for logical HIGH +3 to + 15V for logical LOW

12.3. Data Transfer

Data transmission (MSR ↔ measurement unit) is effected using standardized blocks, each secured with a block check character (BCC).

The characters transmitted here are taken from the USASCII standard character set (0-9, A-Z); check characters are added to the block to facilitate error detection. Maximum block length at present is 256 characters (including control characters and protocol frame).



12.4. Transfer Protocol

Data transmission between the measurement point and the MSR takes place in accordance with a strict master-slave procedure. The measurement site itself never initiates contact with the MSR.

The MSR transmits commands to the measurement site, which then responds with an answer block. All the commands contain an address, i.e. the measurement unit identifier. The addresses can be used to address either the entire measurement site or individual measurement units at the measurement site.

Response blocks also contain from one to four measurement device identifiers for the purposes of identification and allocation.

See section 12.6 for the definitions of the individual telegrams (message blocks).

Data Protocol Structure:

Byte 001:	STX (Start of Text)
Byte 002-nnn:	<TEXT>; Message Text; max. 120 Characters; USASCII coded
Byte nnn+1:	ETX (End of Text)
Byte nnn+2/3:	BCC (Block Check Character)

The response from the measurement site is always in the same format as that of the command it received.

Data Polling

The data registered at the measurement site are transmitted to the MSR in response to a polling request. A polling data block can be used to query either a single measurement unit or all the measurement units connected at a measurement site.

Data Transmission

The data registered at the site are transferred by way of a response message. Where the measurement site has multiple measurement units, the individual values will all be compiled into a single message.

12.5. Generation of the Block Check Character

The block check character (BCC) is generated by forming, byte by byte, the exclusive-or sum of all the characters transmitted (including STX and ETX), starting at \$00. The result byte block (checksum) thus created is transmitted in hexadecimal code wherein the upper nibble of this byte is transmitted as BCC1 and the lower nibble as BCC2.

The ASCII value range of from 0 to 9 and from A to F (capital letters) is permissible for the BCC bytes so that the nibbles can be expressed in hexadecimal notation.

12.6. Telegrams „Serial Measuring Instruments“

In the telegrams cited below the required blanks are depicted with a pound sign (#).

The block control characters and the BCC characters are enclosed in <> for emphasis.

12.6.1. Data Polling of the Measuring Station

Block Identifier: **DA**

Telegram Length: Variable

Telegram Type: Command

Field No.	Start-Byte	Data Format	Description
1	1	<STX>	Start of Text
2	2	DA	Block Identifier
3	4	<ETX>	End of Text
4	5	<BCC1>	Low Nibble BCC
5	6	<BCC2>	High Nibble BCC

12.6.2. Measuring Station Data in Reply to Data Polling

Field No.	Start-Byte	Data Format	Field Description
1	1	<STX>	Start of Text
2	2	MD	Block Identifier
3	4	nn#	Number of Measuring Units
4	7	nnn#	Measuring Unit ID
5	11	±nnnn±ee#	Measured Value
6	20	hh#	Operating Status
7	23	hh#	Error Status
8	26	nnn#	Serial Number
9	30	hhhhhh#	Not Assigned
10	37	nnn#	Measuring Unit #2 ID (optional)
11	41	±nnnn±ee#	Measured Value
12	50	hh#	Operation Status
13	53	hh#	Error Status
14	56	nnn#	Serial Number
15	60	hhhhhh#	Not Assigned
16	67	nnn#	Measuring Unit #3 ID (optional)
17	71	±nnnn±ee#	Measured Value
18	80	hh#	Operating Status
19	83	hh#	Error Status
20	86	nnn#	Serial Number
21	90	hhhhhh#	Not Assigned
22	97	nnn#	Measuring Unit #4 ID (optional)
23	101	±nnnn±ee#	Measured Value
24	110	hh#	Operation Status
25	113	hh#	Error Status
26	116	nnn#	Serial Number
27	120	hhhhhh#	Not Assigned
28	127	<ETX>	End of Text
29	128	<BCC1>	Low Nibble BCC
30	129	<BCC2>	High Nibble BCC

Telegram Identification: MD

Telegram Length: Variable

Telegram Type: Response

13. Technical Specifications

Dimensions and Weight (excluding impactor inlet and antenna)	
Width	320 mm
Height	560 mm
Depth	270 mm
Weight	approx. 15 kg
Power Supply	
Supply Voltage	230 V, 50/60 Hz
Microfuse	T 1.25 A
Power Consumption	approx. 80 W
Electronics	
Interface	RS-232
Transfer Protocol	Bayern-Hessen-Protokoll
Additional Data	
Measurement Range	0 ... 1000 µg/m ³
Resolution	1 µg/m ³
Flow Rate	3.3 l/min (controlled)
Sampling time	Continuous
IP Classification	IP 65

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